AIRCRAFT CARGO COMPARTMENT FIRE TEST SIMULATION PROGRAM

(NASA-CR-151951) AIRCRAFT CARGO COMPARTMENT FIRE TEST SIMULATION PROGRAM Final Report, Oct. 1974 - Jan. 1977 (Douglas Aircraft Co., Inc.) 84 p HC A05/MF A01 CSCL 11D
N78-21223
Unclas
G3/24 15759

R. E. Blumke
McDonnell Douglas Corporation
Douglas Aircraft Company
3855 Lakewood Blvd.
Long Beach, California 90846

NAS2-8699
CR151951-NASA Report Number
January 1977

Final Report for Period October 1974 - January 1977

Prepared for
NASA-Ames Research Center and
Lyndon B. Johnson Space Center

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
MAY 1978
RECEIVED
NASA STI FACILITY

MCDONNELL DOUGLAS CORPORATION

AIRCRAFT CARGO COMPARTMENT FIRE TEST SIMULATION PROGRAM

R. E. Blumke
McDonnell Douglas Corporation
Douglas Aircraft Company
3855 Lakewood Blvd.
Long Beach, California 90846

NAS2-8699
CR151951-NASA Report Number
January 1977

Final Report for Period October 1974 - January 1977

Prepared for
NASA-Ames Research Center and
Lyndon B. Johnson Space Center

MCDONNELL DOUGLAS CORPORATION

1. Report No. NASA CR 151951	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Aircraft Cargo Compartment Fire Test Simulation Program		5. Report Date Jan. 1977
		6. Performing Organization Code
7. Author(s) R. E. Blumke		8. Performing Organization Report No. MDC J7471
		10. Work Unit No. 510-56-01
9. Performing Organization Name and Address McDonnell Douglas Corporation, Douglas Aircraft Company, 3855 Lakewood Boulevard, Long Beach, California 90846		11. Contract or Grant No. NAS2-8699
		13. Type of Report and Period Covered Final Report - 10/74-1/77
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Moffett Field, Ca. 94035		14. Sponsoring Agency Code

15. Supplementary Notes

Technical Monitor, D. A. Kourtides, Chemical Research Project Office, NASA-Ames Research Center, Moffett Field, Ca.

16. Abstract

A cargo compartment simulation facility was utilized for two cargo fire tests. The objective of the 2nd test was to assess fire containment and fire extinguishment in the cargo by reducing the ventilation through the cargo compartment. Parameters which were measured included ignition time, burnthrough time and physical damage to the cargo liner, composition of selected combustible gases, temperature-time histories, heat flux and detector response. The ignitor load was made of a typical cargo consisting of filled cardboard cartons occupying 50% of the compartment volume. Test data and test results are discussed for both tests.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Aircraft Combustion Flammability	Unlimited STAR Category - 24

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	77	

*For sale by the National Technical Information Service, Springfield, Virginia 22151

NASA-C-168 (Rev. 6-71)

PREFACE

An experimental program was established to evaluate the fire containment capability of large cargo compartments. The tests involved a simulated wide-bodied jet cargo compartment. The objective of the tests described in this report was to assess fire containment by evaluation of compartment liner burnthrough, heat flux, temperature profiles, and detector response. This information would establish baseline data upon which additional improvements in fire safety could be designed.

A Douglas Aircraft Company cargo compartment facility at Sacramento, California was utilized. Instrumentation included thermocouples, water cooled calorimeters, smoke detectors, gas samplers, TV and photographic coverage. The compartments were lined with aircraft state of the art fiberglass sheet. Ventilation in the first test was equivalent to the present maximum added to maintain animal life in operating aircraft. In the second test the ventilation was reduced after the smoke detection signal, in accordance with the present airplane operation emergency procedure, to a level corresponding to a typical compartment leakage flow. The ignition load was made up on commonly used packaging material in cardboard cartons occupying fifty percent of the compartment volume.

In the first test the fire was extinguished after 13-1/2 minutes when the steel structure outside the liner reached approximately 320°C (608°F). Two holes burned through the ceiling liner and the liner was extensively delaminated at other locations. In the reduced airflow test the fire was extinguished at two hours; the fire had stabilized with structure temperature approximately 320°C (608°F) after reaching a maximum of 335°C (635°F) at one hour. A split occurred in the ceiling liner and extensive areas were delaminated.

It is recommended that one other baseline test utilizing freon agent, when ventilation is shut down, be performed before tests, that will introduce and evaluate improved liner materials and protection systems.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

I. INTRODUCTION

Research efforts to improve the margin of fire safety of cargo compartments was considered an integral part of a general aircraft fire safety improvement program by the National Aeronautics and Space Administration and by the Douglas Aircraft Company. This program was therefore initiated wherein baseline tests were to be conducted to define the areas where further development effort should be concentrated to optimize the fire containment capability of cargo compartments for large commercial aircraft. The research test work described in this report on cargo compartments was performed at the McDonnell Douglas Corporation Test Facility at Sacramento, California on June 5, 1975 and July 21, 1976.

Aircraft cargo compartments, because of their proximity to passengers and fuselage structure are designed to avoid or contain accidental fires. While such fires are generally rare and successfully controlled, efforts continue to minimize the possibility of such an incident.

Fire prevention for small compartments rely on containment and self-induced smothering. This involves air leakage control, which becomes impractical with larger compartments that have large loading doors. Another means of fire control is smoke and fire detection and subsequent quenching or extinguishment of the fire by an active fire extinguishing system. The main objective for all compartments is to confine the fire within the walls of the cargo compartment until a landing can be effected, the cargo pulled out so that ground fire fighting equipment can be used. The nature of fires occurring in cargo compartments has not been fully defined, neither has the degree of "hardening" required to most effectively contain or extinguish the fire. The selection of the two baseline tests were based on compartment volumes larger than that covered by the present FAA FAR 25 Class D regulation that requires restricted air leakage and fire resistant liners to smother and confine fire in small compartments. The baseline selections were also made to enable comparison of improvement features with the present day fire protection. Test No. 1 was established with the following parameters:

- o Ventilation typical of that supplied for animals in certain Class C compartments, i.e., approximately 20 air changes/hour for the test compartment's 2000 cu. ft. volume.
- o A fifty percent compartment volume container loading.
- o Duration of the test such that ventilation and fire be allowed to continue beyond failure of the representative contemporary ceiling liner.

Test No. 2 was to establish the degree of fire containment of the aircraft cargo compartment by conducting a similar test as described above except with reduced ventilation after smoke detection in order to assess ventilation control as a means for controlling cargo fires. Additional detectors were tested for a comparison with the previously tested smoke detectors and consisted of "off-the-shelf" infrared and a combined infrared and ultraviolet detection unit.

2.0 DISCUSSION

2.1 PURPOSE

The baselines were selected to test under floor cargo compartments of wide-bodied jet transports under conditions of intense fires. The compartments investigated were the large or ventilated compartments designated as Class C by the FAA which require air shutoff, detection, and fire extinguishing agent. The air shutoff and agent fire protection features were not utilized in the compartment during the first baseline test so that containment margins without the use of these design features could be determined.

The air shutoff was simulated in the second test. These test configurations are not completely representative of flight hardware but provided the necessary steps in understanding and defining the cargo fire. Baseline tests were selected to allow comparison of improvement features with present protection standards. As further fire protection measures are incorporated in later tests, direct comparisons can be made to determine the increased margin of protection obtained.

2.2 TEST FIXTURE

The fixture was made from a steel framework of 3.81 cm X 7.65 cm x .164 cm (1.5 in x 3 in x .065 in) rectangular beams on 50.8 cm centers (20 inch centers). Typical aircraft quality fiberglass epoxy liners were attached to the beams with .749 cm (5/16 in) aluminum rivets and 1.91 cm diameter (.75 in dia) washers approximately 15.24 cm (6 in.) apart. The ceiling liner was .584 mm (.023 inches) thick per Douglas Material Specification 1946.

The compartment floor was steel and not representative of aircraft floors as previous test experience had indicated that cargo floors are not adversely affected by cargo compartment fires. The fixture roof above the ceiling liner was also of steel. Two windows were installed in the main door, one for a TV camera (first test), 16 mm camera (second test) and the other for visual observation.

Airflow was supplied behind one sidewall liner to simulate ventilation down the tunnel area of an aircraft. This ventilation, although external was considered a possible factor affecting the fire resistance of the adjacent cargo wall liners. Internal compartment ventilation was provided by drawing air out near the front of compartment and allowing air to enter near the rear of the compartment through a 30.48 cm diameter (12 inch diameter) hole in the liner. Both inlet and outlet were near the floor on opposing sidewalls.

The fixture was equipped with an industrial type CO_2 firex system which would be used to knock down the fire at the end of the test. The cargo would then be pulled from the fixture and the fire completely extinguished with water. See Figure 1, for overall view of Cargo Compartment Simulator.

2.3 TEST CONFIGURATION

The detailed configuration for the two tests were as follows:

Length:	8.13m (26'-8")
Height:	1.70m (5'7")
Width:	3.84m (12'-7")
Volume:	$56.64m^3$ (2000 ft^3)
Target Ventilation:	20 changes/hr = 1387.76 Kg/Hr (3060 lbs/hr) .6 changes/hr = 41.41 Kg/Hr (91.3 lbs/hr) on detection
Actual Ventilation:	First Test - 21 changes/hr = 1366.4 Kg/Hr (3013 lbs/hr) at 32.2°C (90°F) Second Test - 20.2 changes/hr = 1201.8 Kg/Hr (2650 lbs/hr) at 25.6°C (78°F) reduced to .7 changes/hr - 46.35 Kg/Hr (102.2 lbs/hr) on detection
Target Tunnel Flow:	5442.8 Kg/Hr (12,000 Lbs/Hr)
Actual Tunnel Flow:	First Test - 5447.6 Kg/Hr (12,012 Lb/Hr) at 32.2°C (90°F) Second Test - 5442.8 Kg/Hr (12,000 Lb/Hr at 32.2°C (90°F)
CO_2 Firex Backup System:	130.1 Kg (300 lbs)
Ignition Source:	Gas soaked rag and two hot wires

Cargo Load:	50% gross compartment volume 28.32m^3 (1000 ft^3)
Cargo Composition:	45.72cm x 45.72cm x 45.72cm (18" x 18" x 18") cardboard cartons loosely filled with current commercial type packing material (e.g., rubberized hair, polyethylene, polyurethane, cellular film, fiber board, and Kim Pac), see Figure 2
Cargo Liner:	.584mm (.023 in) epoxy fiberglass per Douglas Spec DMS 1946

The cargo was loaded on four pallets which were linked together and attached by cable to a fork lift. The boxes were piled three high except adjacent to the camera where the three top boxes were removed to improve the field of vision (first test only), and above the ignition source. (See Figure 3.)

The ignition source was made up of two pieces 45.72 cm (18 inches) of inconel wire wound into a loose coil and mounted to a transite strip. Two boxes were removed from the cargo at point B in Figure 4 and 5, creating a vertical chimney 45.72cm square and 91.44cm deep (18 inches square and 36 inches deep). The two independent ignition coils were laid on top of the remaining box. A gasoline soaked rag approximately 30.48cm square (12 inches square) was placed over both coils. Two of the boxes which formed one wall of the chimney were opened and the packing material pulled half way out to allow the flames from the fire to lick the packing and ensure ignition of the cargo load.

Both of the coils were connected to a 20 amp DC Variac. The rag was ignited by applying 7.35 amps to each of the coils.

2.3.1 TEST CONFIGURATION - DISCUSSION

2.3.1.1 Selection of Ignition Source & Fireload

Cargos, packaging and load arrangements vary so much that it is impossible to visualize a typical fire load or form of ignition. The ignition source selected for these baseline tests was one that would cause initial smoldering then erupt into a small flame to ignite the cargo packing material. The dual coil ignition source and gas soaked rag was found to be the most effective method to achieve this. This type of test ignition source would not overpower the instrumentation to the extent that comparative data or other factors would be difficult to extract.

It is an FAA requirement that aircraft systems incorporating possible ignition sources be safeguarded or excluded from cargo compartments. FAA (NAFEC) baggage compartment tests have demonstrated the difficulty of fire progress through suitcases, etc. (Reference 1) due to material density, production of moisture and smoke replacing oxygen. It is seldom that self-igniting sources, and combustible material are packaged intimately, due to the restrictive packaging requirements for hazardous material. These factors, plus the need to carry densely loaded cargo (with inherent smothering characteristics), ensures that the occurrence of an ignition and sustained burning is very unlikely.

Packaging material as found in a survey of a typical cargo airline at Los Angeles International Airport was used for the fire load. Chimneys were left to enable flame spread from deliberately loosened fire load material near the ignition source, and the igniter coils were supplemented by a gasoline soaked rag.

Ignition was immediately achieved in an externally located demonstration of the ignition process before both tests but there was insufficient current to each coil to achieve ignition for the second test with the coils located in the simulator. Previous tests had established that a minimum current of 7.35 amps was necessary to each coil to ensure ignition. This amperage was not obtained during the first three attempts for ignition in the second test. A check of the amperage indicated that only 5.6 amps were reaching the coils. This was due to the fact that both 16 mm cameras were also being operated from the same power source. The power to the ignition coils was increased to 7.35 amps, resulting in a successful ignition.

Although giving the appearance of more load (Reference Figure 3) the actual volume occupied by the cardboard boxes was 50 percent of the unoccupied cargo compartment volume. A 50 percent loaded configuration was selected in FAA tests (Reference 2) "in order to simulate a fire condition in a compartment filled to its usable capacity". The major requirement for the fire load material was that it was reasonably reproducible in quality to better enable the different fire conditions in different tests to be identified. There was, therefore, no need to detail chemical composition when burning only to show fire characteristic differences. Toxic gas content readings were not taken, because of the many variations possible in actual cargo and because design precautions are taken to ensure that cargo fumes are kept out of occupied areas. These precautions include differential pressure flow and provision of ducting to provide safe exit paths. These precautionary measures are confirmed by measurements taken during flight test.

2.3.1.2 Ventilation Selection

The large local air inlet used in both tests (Figure 6) was representative of aircraft inlets used to supply ventilation flow. This inlet is normally closed off as a part of the fire emergency drill; any airflow is then out of the compartment through loading door leaks and in through leaks in liner seams or from flapper valves installed to balance pressure between the cargo compartment and aircraft interior during altitude changes.

During the first test this fire emergency drill was not followed. The air inlet was left open for the duration of the test and the ventilation rate of 21 changes/hour was held constant. This procedure allowed full definition of the airflow effect on cargo compartment fires which was the objective of the test.

To simulate the fire emergency drill in the second test several actions were taken. The air inlet remained open until smoke detection with 20.2 changes/hour airflow through the compartment representing the maximum ventilation rate. Upon smoke detection a flat plate was positioned near the air inlet as shown in Figure 7. The ventilation rate was quickly reduced to 0.7 changes/hour; which simulated the leakage rate through cargo doors, liner seams, and flapper valves. Normally this small leakage rate cannot be felt in such a large volume but during the test local flaming became evident at the inlet.

It became apparent through observation that more than the normal leakage airflow was entering the inlet due to external wind conditions. This extraneous air contributed to the flaming condition adjacent to the inlet. This local fire convection effect emphasizes the necessity to provide check valves at ventilation inlet duct holes in aircraft installations - a feature that in the past had been thought by some to be redundant when the system is shutoff by other means. It also highlights the need to replace access or blowout panels and to change cargo liners that are damaged during cargo loading.

The ventilation rate of 20 changes per hour was selected as being the maximum rate in present wide-bodied jets supplied to keep cargo fresh and maintain animal life. The leakage rate of 0.7 changes/hour was conservatively assessed based on lower cargo compartment leakage rate flight tests conducted on one wide-bodied jet.

2.4 INSTRUMENTATION

Instrumentation List, Test No. 1

- o Three Pyrotector smoke detectors, P/N 30-231-17
- o Four chromel-alumel air temperature thermocouples 2.54cm (1 in.) below ceiling
- o Four chromel-alumel liner temperature thermocouples (on ceiling)
- o Two chromel-alumel structure temperature thermocouples (above ceiling)
- o One 0-.035 Kg/cm^2 ΔP (0-0.5 psi ΔP) pressure transducer in sidewall
- o One each, O_2, CO_2, CO gas analyzers plus grab samples
- o Two orifice plate flowmeters for tunnel flow and ventilation
- o One 16 mm motion picture camera, one infrared video tape camera, plus still photos
- o Total hydrocarbon samples
- o Two water cooled Thermogage calorimeters (NASA supplied)
- o NASA supplied smoke meter

The location of the instrumentation is shown in the plan view schematic of Figure 4. Customary units were used for all instrumentation measurements.

Instrumentation List, Test No. 2

- o Three Pyrotector smoke detectors, P/N 30-231-17
- o Two Fenwal U.V. detectors, P/N 10-190017-102
- o Two Pyrotector UVIR detectors, P/N 30-207-25

- o Eight chromel-alumel air temperature thermocouples 2.54 cm (1 in.) below ceiling
- o Ten chromel-alumel liner temperature thermocouples (on ceiling)
- o Two chromel-alumel structure temperature thermocouples (above ceiling)
- o One 0-.035 Kg/cm^2 ΔP (0-0.5 psi ΔP) pressure transducer in sidewall
- o One each O_2, CO_2, CO gas analyzers plus grab samples
- o Two orifice plate flowmeters for tunnel flow and ventilation
- o Two 16 mm motion picture cameras plus still photos
- o Total hydrocarbon samples
- o One water cooled Thermogage calorimeters (NASA supplied)

The location of the instrumentation is shown in the plan view schematic of Figures 5, 8 and 9.

2.5 GAS SAMPLING

<u>Gas Sampling - Test No. 1</u>

(a) Model 802 Oxygen Analyzer - MSA
(b) Model 303 Lira CO Infrared Analyzer - MSA
(c) Model 511 Gas Chromatograph - Analytical Instrument Development
(d) Model 512 Gas Chromatograph - Analytical Instrument Development
(e) Model MB41 Bellows Pumps - Metal Bellows Corp.
(f) Tri-Flat Flowmeters - Fisscher & Porter
(g) Model T171B Strip Chart Recorders - Esterline Corp.
(h) Model 725-3Cs Strip Chart Recorders - Mast Development Co.
(i) Model 2122 Temperature Recorder

<u>Gas Sampling - Test No. 2</u>

(a) Model 802 Oxygen Analyzer - MSA
(b) Model 303 Lira CO Analyzer - MSA
(c) Model 864 CO_2 Analyzer - Beckman
(d) Model 511 Gas Chromatograph - Analytical Instrument Development
(e) Model 512 Gas Chromatograph - Analytical Instrument Development
(f) MB21 Bellows Pumps - Metal Bellows Corp
(g) Model 212 Heat/Line Hose - Technical Heaters, Inc.
(h) #2014 Micro Volume Sampling Valve - Carle Instruments

Location of the sampling probes are shown in Figures 10, 11 and 12.

2.6 FIRST TEST DESCRIPTION

At time zero, power was applied to the ignitors. Approximately one minute and ten seconds later flames erupted. Less than a minute after the flames were observed, smoke obscured both visual and camera observation of the fire.

The ventilation rate was held constant for the duration of the test in order to allow full definition of airflow effect. Although the rate was selected as being the maximum in contemporary aircraft and representative of at least one wide-bodied jet, the procedure of maintaining the rate after detection is not representative of present mandatory emergency procedures.

Gas samples were taken and temperatures wwere monitored throughout the test. Large quantities of smoke came from the compartment and at times disrupted personnel thus interfering with the gas sampling. The ambient temperature was 32.2^{o}C (90^{o}F), barometric pressure was 75.69cm Hg (29.8 in. Hg), and wind from the West was 7.42 Km/Hr (4 knots).

The test was terminated at approximately 13-1/2 minutes by shutting off ventilation and discharging the CO_2 firex system. The bulk of the cargo was then pulled from the compartment and extinguished with water. The last half pallet of cargo was damaged by the fire and did not pull out of the compartment. As a result, a fire hose had to be directed into the compartment to quench this last portion of the burning cargo.

2.7 FIRST TEST - DISCUSSION OF RESULTS

Temperature, heat flux, and gas concentration curves relate the time history of the fire for Test No. 1 and are shown in Figures 13 through 27. These same figures also relate the time history of the fire for Test No. 2 for the first thirteen minutes. These curves will be discussed further in this report to compare test results between Test No. 1 and Test No. 2.

The center smoke detector responded 66 seconds after power was applied to the coil, and the forward smoke detector responded 2 seconds later. The aft smoke detector responded 76 seconds after power was applied. Smoke buildup was rapid; the smoke meter showed total obscuration at approximately 90 seconds. The pressure transducer recorded no change in compartment pressure during the first 9 minutes of the test. At that time the sensing line was damaged by heat and no further data was taken.

The fire progressed from the ignition source at point B, Figure 4, toward the vent inlet. Flames were observed through the ventilation inlet opening during most of the test. No flash fire occurred. The air temperature plots show an initial temperature peak at the time the flames were first visible through the windows. The air temperature then decayed for about 1-1/2 minutes before climbing again. Each location exhibited the same general temperature profile in a different time sequence, depending on the distance from the ignition source. The liner temperature plots closely follow the shape of their respective air temperature plots, but at a lower level and with less fluctuation. The heat flux, watt/m^2 (BTU/ft^2-sec) plot follows the same profile as the respective temperature plots.

Figures 23 through 27 relate the concentrations of oxygen, carbon dioxide, carbon monoxide, total hydrocarbons (as urethane), and methane as a function of time. Oxygen and total hydrocarbons were essentially monitored continuously while the values for the other three constituents were derived from the eight grab samples. (The continuous monitor for carbon monoxide went off scale at the two-minute mark.) These graphs are adjusted for the time lag associated with the sampling lines. From Figure 23 it is evident that after 9 minutes the fire characteristics were dominated by the availability of oxygen which in turn was controlled by the ventilation rate. This suggests that equilibrium conditions for the combustion process within the cargo compartment had been obtained.

Post-test examination revealed two holes burned through the ceiling liner adjacent to the vent inlet. The holes were approximately 55.88cm x 55.88cm (22 x 22 inches) and 25.4cm x 50.8cm (10 x 20 inches) as shown in Figures 4, 28 and 29. Though extensive areas of the ceiling and sidewall liner were delaminated and baked free of resin, no other burnthroughs existed.

Review of the photographs taken during the test and examination of the cargo load after the test indicates the possibility of flammable gas having been evolved in the vicinity of the ignition source and migrating toward the ventilation inlet. The gas then mixed with the incoming oxygen and burned locally in the open spaces near the inlet, eventually causing the liner burnthrough. Evidence was found of deep seated burning at the ignition source, but the liner above the ignition source was not damaged as much as would have been expected had the final combustion process occurred there.

2.8 SECOND TEST DESCRIPTION

The second test was conducted in the same manner as test number one except for reducing the airflow through the compartment after detection. Prior to the test a demonstration was conducted outside the compartment to show the ignition technique and the type of cargo load used in this test. Refer to Figure 2.

At time zero, power was applied to the ignitors. The first three attempts to ignite the gas soaked rag failed and the compartment had to be opened each time and a new rag placed over the ignitors. On the fourth attempt ignition of the rag occurred and subsequent cargo ignition. The reason for ignition failure was previously explained in Section 2.3.1.1. Smoke build-up within the compartment was very gradual and flames did not occur until three minutes twenty seven seconds after the ignitors were energized. The airflow through the compartment was reduced to .7 changes/hour when smoke detection was indicated.

Gas samples were taken and temperatures were monitored throughout the test. Smoke seeping from the compartment through areas other than the tunnel and ventilation air exits was minimal and presented no hazard to test or spectator personnel.

The test was terminated at 2 hours by shutting off ventilation and discharging the CO_2 fire extinguishing system. The cargo load was then withdrawn from the cargo compartment and extinguished with water.

2.9 SECOND TEST - DISCUSSION OF RESULTS

The temperature, heat flux, and gas concentration curves for the cargo compartment environment throughout the test are shown in Figures 30 through 51. The ultraviolet-infrared (UVIR) detector at position B over the fire (see Figure 5) responded at three minutes twenty-seven seconds (3:27) and the smoke detector in the same location responded 5.5 seconds later. At this time the airflow through the compartment was reduced from 20.2 changes per hour to 0.7 changes per hour. The ultraviolet detector in the forward position did not respond during the test. Refer to Table No. 1 for response time of the detectors. At approximately 3.5 minutes after the ignitors were switched on the temperature within the compartment began to rise. Visual observation of the inside of the compartment was discontinued at approximately 4.0 minutes due to obscuration by smoke build-up. The outside movie camera was shut off approximately 4 minutes after time zero. The pressure transducer trace recorded no pressure change during the test, indicating that no flash fire occurred.

Flames were observed at the ventilation inlet at five minutes after time zero and continued during the test.

The temperature plots for thermocouple locations A, B, C and D (Figure 9) show a large initial temperature increase at approximately the same time and the UVIR signalled flame detection (3:27), followed by a rapid decrease and general temperature stabilization, Figures 30 through 39. The air thermocouples in locations A and B remained the highest at approximately 500°C (932°F); (Figures 33 and 34) during the remainder of the test. The highest emperature of 590°C (1094°F) was reached on the air thermocouple at location B directly over the ignition source. The structural temperature increased less rapid at location B, reaching maximum of 335°C (635°F) during the duration of the test; Figures 30 and 31.

The temperature plots for thermocouple locations, E,F,G,H,J and K (Figure 9) displayed the same general characteristics but several minutes later; Figures 40 through 49. The air thermocouple at location F, Figure 42, read the highest at 880°C (1616°F). After the initial peaks were reached in these areas the decrease of temperature was much less than at the forward locations toward the air vent outlet. This indicates that the fire in the earlier stages was localized in this area (source of oxygen) as was evidenced by the flame at the inlet and post test examination of the ceiling liner. A general decrease in temperature in this area and stabilization of the temperatures in locations A, B, C and D beyond the first 60 minutes

DETECTOR	LOCATION	TIME(Min:Sec)
UVIR	Center (over fire)	3:27
Smoke detector	Center (over fire)	3:32:5
UVIR	AFT	3:35
Smoke detector	AFT	3:37
U.V.	Center (over fire)	3:38
Smoke detector	Forward	3:44
U.V.	Forward	No detection

TABLE No. 1 RESPONSE TIME OF DETECTORS IN COMPARTMENT indicates that the fire was progressing towards the forward portion of the compartment. The convection currents due to the heat generated by the fire appears to have had more effect on temperature distribution than the airflow through the compartment. The highest temperatures occurred at the thermocouples located above the fire rather than towards the air outlet. This is indicated by the oscillations occurring in the temperature profile curves.

Figure 51 indicates that the oxygen content of the cargo compartment diminished rapidly between 5 and 15 minutes, leveling off at 1% for the duration of the test. An apparent flareup occurred (and is revealed in the oxygen, hydrocarbon data and most thermocouple locations) at about 25 minutes when the plate over the inlet came loose for a time allowing additional air into the compartment. The CO/CO_2 ratio data is low, about 0.25 up to 75 minutes, then about 0.05 to the 2 hour mark.

At 60 minutes the fire within the compartment began to stabilize as the oxygen content was reaching its lowest level of 1%. This of course was the limiting factor in the development of the fire from then on. This is indicated by the decrease of the CO, CO_2 and increase of the total hydrocarbons. The gas sampling location was about 20 feet from the fire location and the gases represent a composite of the downstream gases of the fire effluent.

Methane represented about one third (1/3) of the total hydrocarbons produced. The remaining hydrocarbons would be heavier varieties produced in the pyrolytic processes, most probably from the rubberized hair and the polyurethane.

Figures 52 through 56 show the ceiling liner damage. The greatest damage occurred adjacent to and in front of the airflow inlet where the fire was centered. The ceiling area over the ignition source did not burn through. When the resin in the fiberglass bakes free only the fiberglass mat remains. This mat without the resin has little strength. The weight of the fiberglass panel causes the structural attachments to shear through the mat and the panel falls and hangs into the compartment, see Figure 53. New design techniques for attachment should be considered and tested in future programs. A split 7.62cm x 33cm (3 in. x 13 in.) occurred in the ceiling

1.42m (56 in.) forward of the aft bulkhead and .81m (32 in.) in from the right hand side. A small piece of fiberglass was also hanging 3.25m (128 in.) from the aft bulkhead .61m (24 in.) long. Refer to Figures 53 through 56.

Extensive areas of the ceiling were delaminated and baked free of resin but no other burnthoughs existed. The sidewall liner above the inlet also showed delamination and was baked free of resin but no burnthroughs; see Figure 6. Although the resin bakes free from the fiberglass the mat remains and provides an effective barrier against flame penetration.

During the test smoke was observed locally, at one bulkhead section, seeping through panel gaps and forming scorch marks along the outer edge of panels; this smoke would normally be cleared away, i.e., scrubbed, by the tunnel airflow but, as noted in the test simulator description, the tunnel air was only represented on one side.

The present requirement for detectors is that an early warning be provided to allow emergency action to be taken and the aircraft directed to an emergency landing. Destruction of the detectors from the heat of the fire early after the initial warning, in no way diminishes their value as an early warning device.

2.10 COMPARISON OF TEST RESULTS BETWEEN TEST NO. 1 AND TEST NO. 2

The temperature curves in Figures 13 through 21 compare the temperature profiles between Test No. 1 and Test No. 2 for the first 13 minutes for each test. Test No. 1 was terminated at that time. In all locations A through D the temperatures in Test No. 1 recorded higher readings indicating a more severe fire. Airflow through the compartment during the first test was held constant at 21 changes per hour instead of being reduced to .7 changes per hour indicating that the effects of additional air is to cause a more severe cargo fire.

The structure temperatures as shown in Figure 13 show approximately the same slope but at 13 minutes test number one had a ΔT of 130°C (266°F) above test number two. Air and liner temperatures during tests number one in locations A through D were all higher than test number 2 with average maximum ΔT's of 111°C (232°F) and 134°C (273°F), respectively. In both tests the liner temperatures were less than the air temperatures. The temperature profiles between Test No. 1 and Test No. 2 are very similar showing the repeatability of the cargo fire test simulator.

In both tests the fire migrated towards the ventilation inlet (source of oxygen) and in both tests the most severe ceiling liner damage occurred between the ignition source and ventilation inlet; this was also where the highest temperatures occurred in locations E through K. This area was only instrumented in the second test so a direct comparison between the two tests cannot be made.

Figure 23 through 27 compare the gas sampling readings during Test No. 1 and Test No. 2 for the first 13 minutes. Comparison of oxygen concentrations (Figure 23) between the first and second tests signifies that the combustion process was more complete during the first test. Considering the high ventilation rate (21 changes/hour) during the first test the oxygen concentration should have been much higher, had oxygen not been consumed by a very active fire. During the second test with the ventilation rate reduced (0.7 changes/hour) the oxygen concentration remained relatively high compared to the first test, suggesting that the oxygen reaching the fire was insufficient to support a more active combustion process. This is also indicated, as stated above, by the higher temperatures that were obtained in the compartment during the first test. Figure 51 shows gas concentration data for the complete two hours during the second test.

3.0 CONCLUSIONS

3.1 SUMMARY OF CONCLUSIONS

The following conclusions have been formulated on the basis of the test results.

Test No. 1

For large volume (2000 ft^3) highly ventilated cargo compartments without provisions for ventilation shutoff:

- o The ceiling appears to have the least margin for burnthrough and should therefore be fabricated from a more fire resistant material.
- o Sidewall integrity appears to be adequate against burnthrough.
- o The fire spread generally, but tended to progress more toward the source of air.
- o Temperatures stabilized after 5 or 6 minutes near the ignition source, and after 9 minutes at remote locations.
- o Structural temperatures climbed steadily until the CO_2 was released.
- o Flame occurred and temperatures increased for at least 9 minutes.

Test No. 2

For large volume (2000 ft^3) highly ventilated cargo compartments with reduced ventilation after smoke detection:

- o The ceiling still appears to have the least margin for burnthrough.
- o Sidewall integrity remains adequate against burnthrough.
- o The fire spread generally, localizing towards the source of air during the test, then moved from the fire source region to involve the entire length of the cargo.
- o Temperatures throughout the compartment reached their highest values during the first 60 minutes then either stabilized or began to decrease.
- o Structure temperatures climbed steadily for the first 60 minutes then stabilized.

- Temperatures at all locations during Test No. 2 (that could be compared) were lower than Test No. 1 during the first 13 minutes.
- Reduction of airflow through the compartment reduced the intensity of the fire when compared to Test No. 1.
- Response time for the visual detectors was less than the smoke detectors, but the smoke detectors remain very satisfactory.

Fire protection systems and airflow shutoff procedures such as on present day aircraft, and/or more fire resistant ceiling liners than epoxy fiberglass are essential for containment. Based on these test results liner materials should be developed that could withstand at least $800^{\circ}C$ ($1472^{\circ}F$); fasteners should be capable of retaining heat affected liners.

4.0 RECOMMENDATIONS

4.1 SUMMARY OF RECOMMENDATIONS

The following recommendations are made based on the results of these tests:

- o Conduct a third test with aircraft type fire extinguishing following ventilation control.
- o Investigate high temperature lining in the ceiling area to supplement the other fire protection measures.

5.0 REFERENCES

1. Asadourian, L. A.: Evaluation of Flight Fire Protection Means for Inaccessible Aircraft Baggage Compartments. Technical Development Report No. 146, Civil Aeronautics Administration, June 1951.

2. Gassman, Julius J.; Hill, Richard G.: Fire Extinguishing Methods for New Passenger/Cargo Aircraft FAA-RD-71-68, November 1971.

FIGURE 1. CARGO COMPARTMENT FIRE SIMULATOR

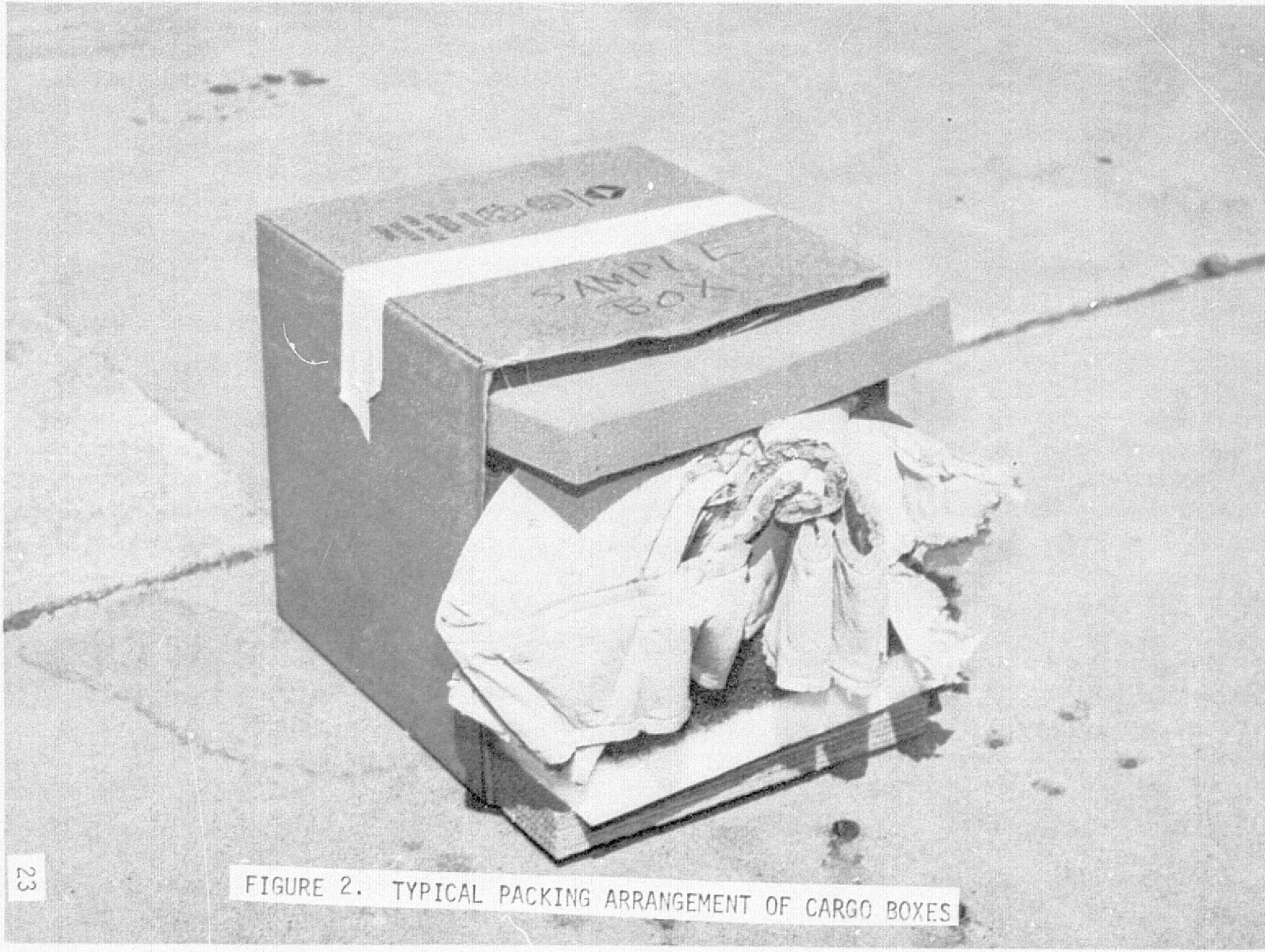


FIGURE 2. TYPICAL PACKING ARRANGEMENT OF CARGO BOXES

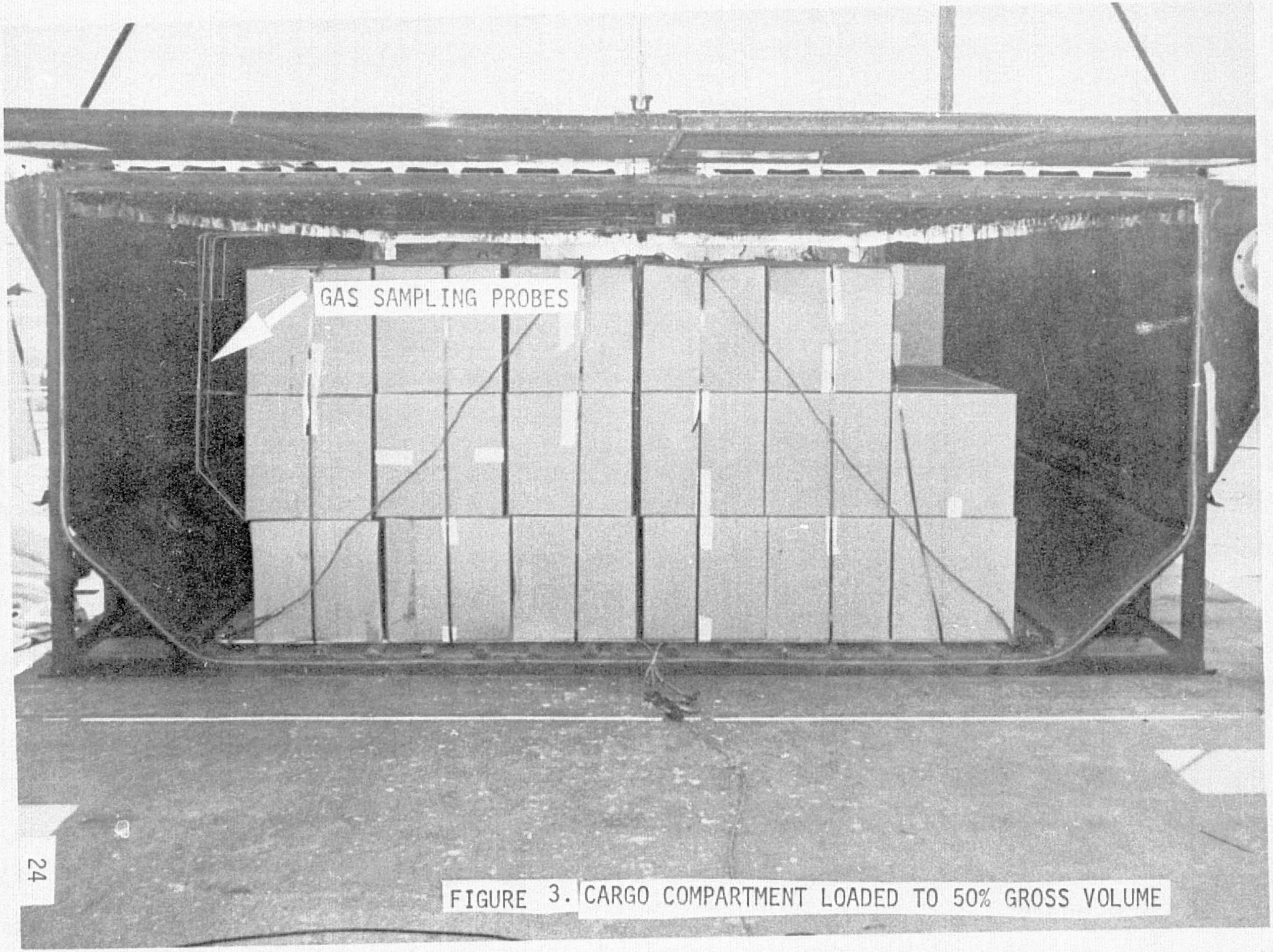
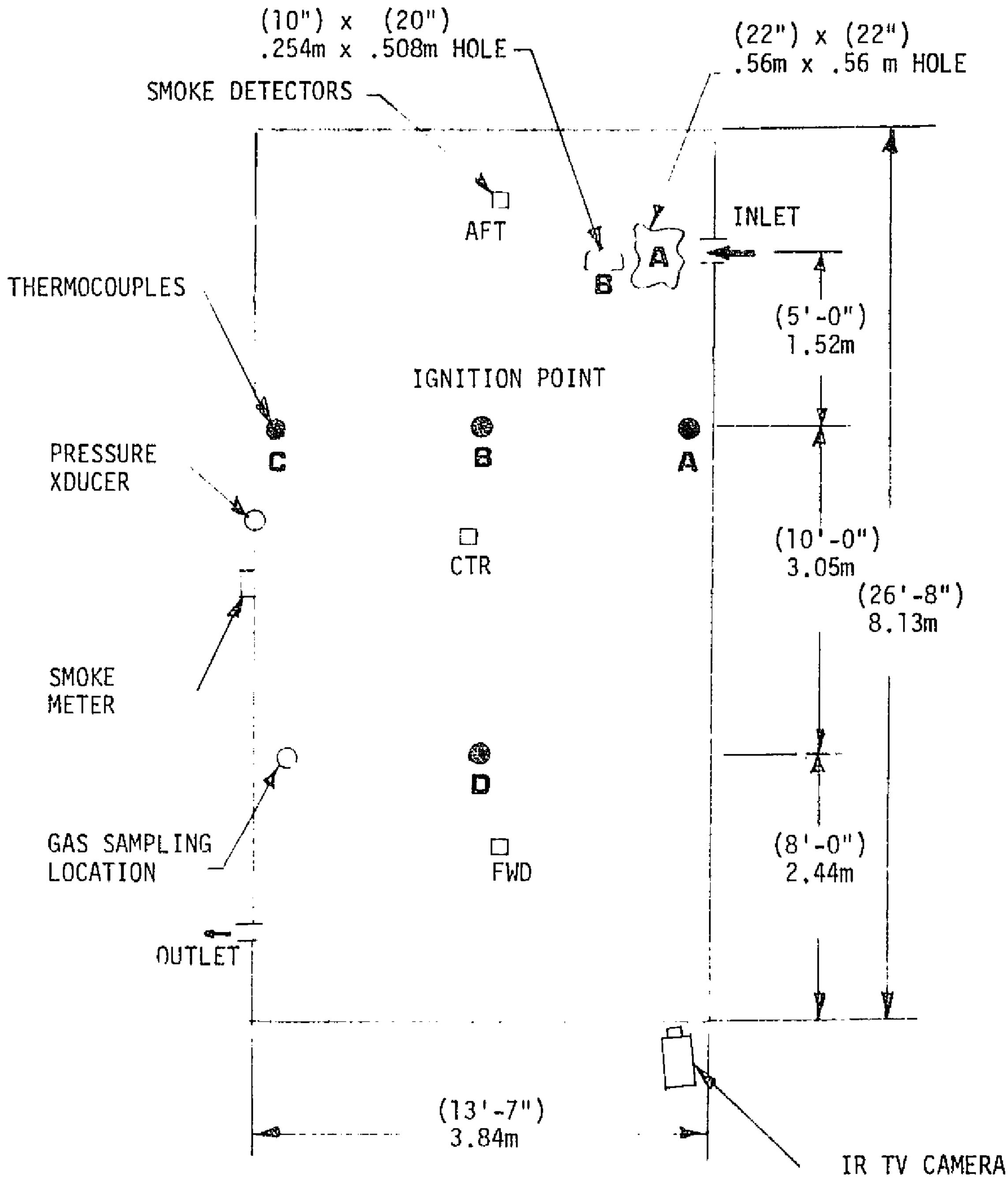


FIGURE 3. CARGO COMPARTMENT LOADED TO 50% GROSS VOLUME



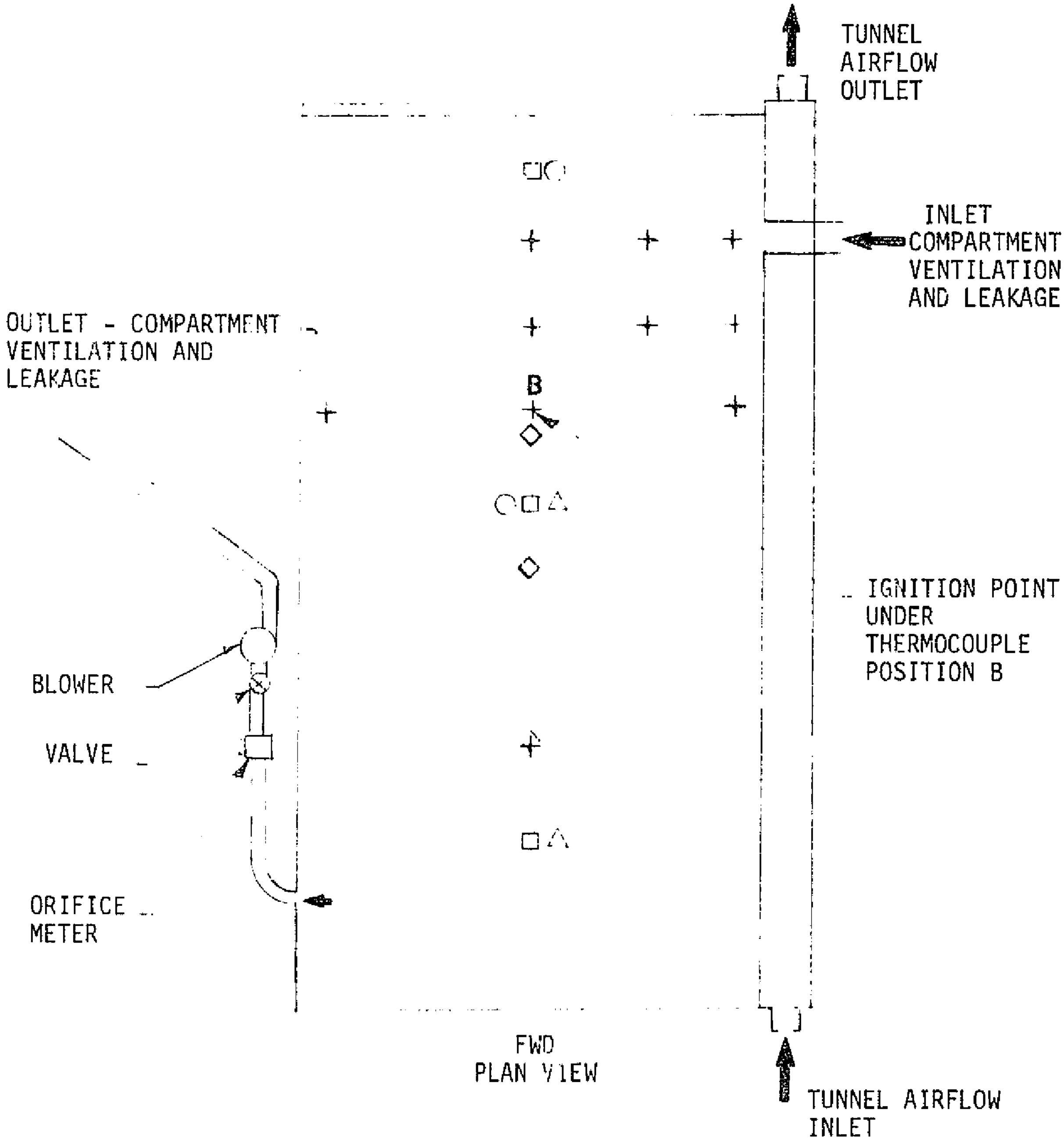
A - AIR AND LINER T.C.

B - AIR, LINER AND STRUCTURE TC; CALORIMETER; IGNITION

C - AIR AND LINER TC

D - AIR AND LINER TC; CALORIMETER

FIGURE 4. SCHEMATIC OF COMPARTMENT INSTRUMENTATION SHOWING RELATIVE LOCATIONS, AND DAMAGED CEILING AREAS - TEST NO. 1



□ SMOKE DETECTORS

○ ULTRAVIOLET INFRARED DETECTORS

△ ULTRAVIOLET DETECTORS

◇ CALORIMETERS

▭ PRESSURE PICKUP

+ THERMOCOUPLES

FIGURE 5. SCHEMATIC OF COMPARTMENT INSTRUMENTATION SHOWING RELATIVE LOCATIONS - TEST NO. 2

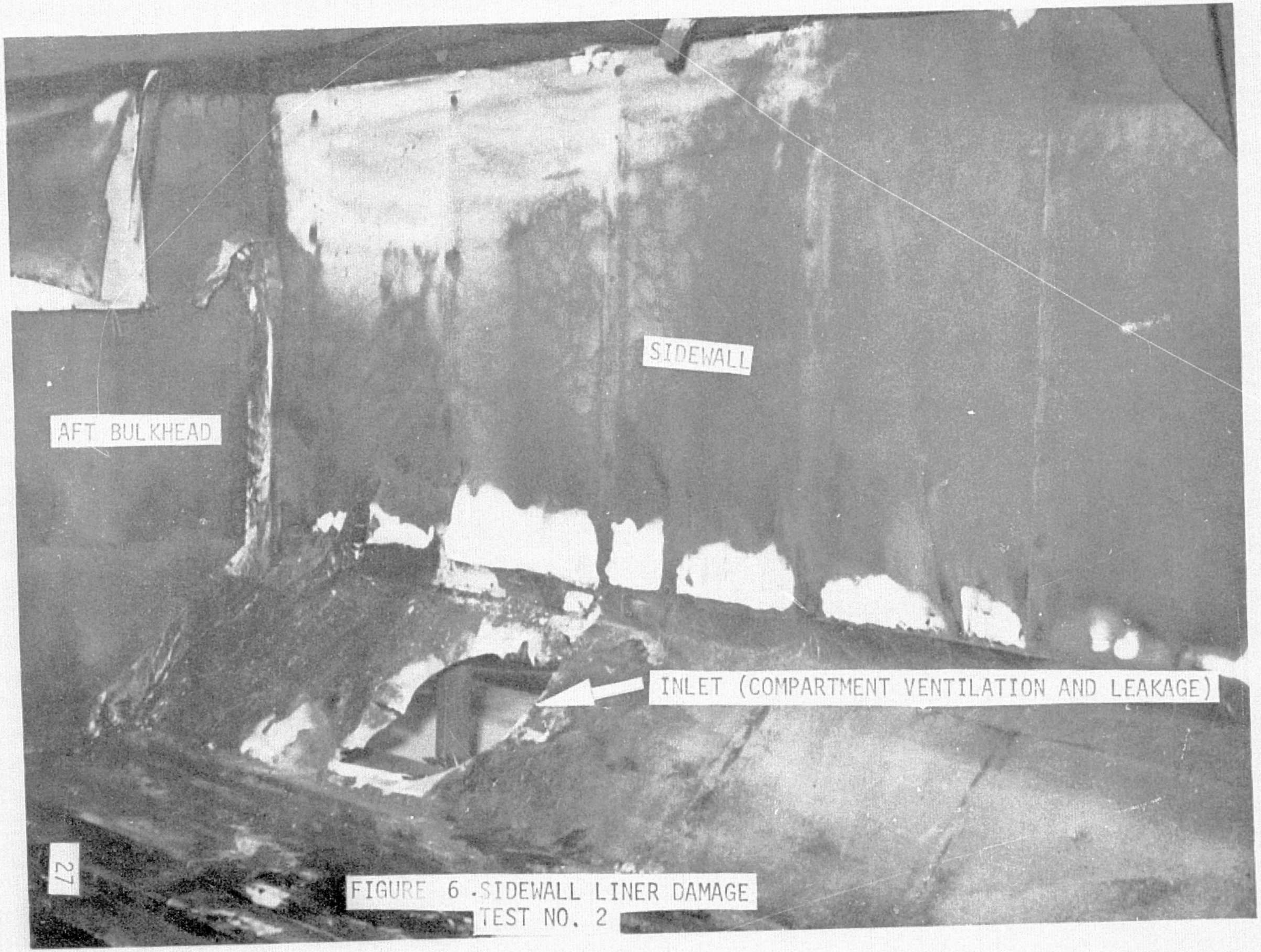


FIGURE 6 .SIDEWALL LINER DAMAGE
TEST NO. 2

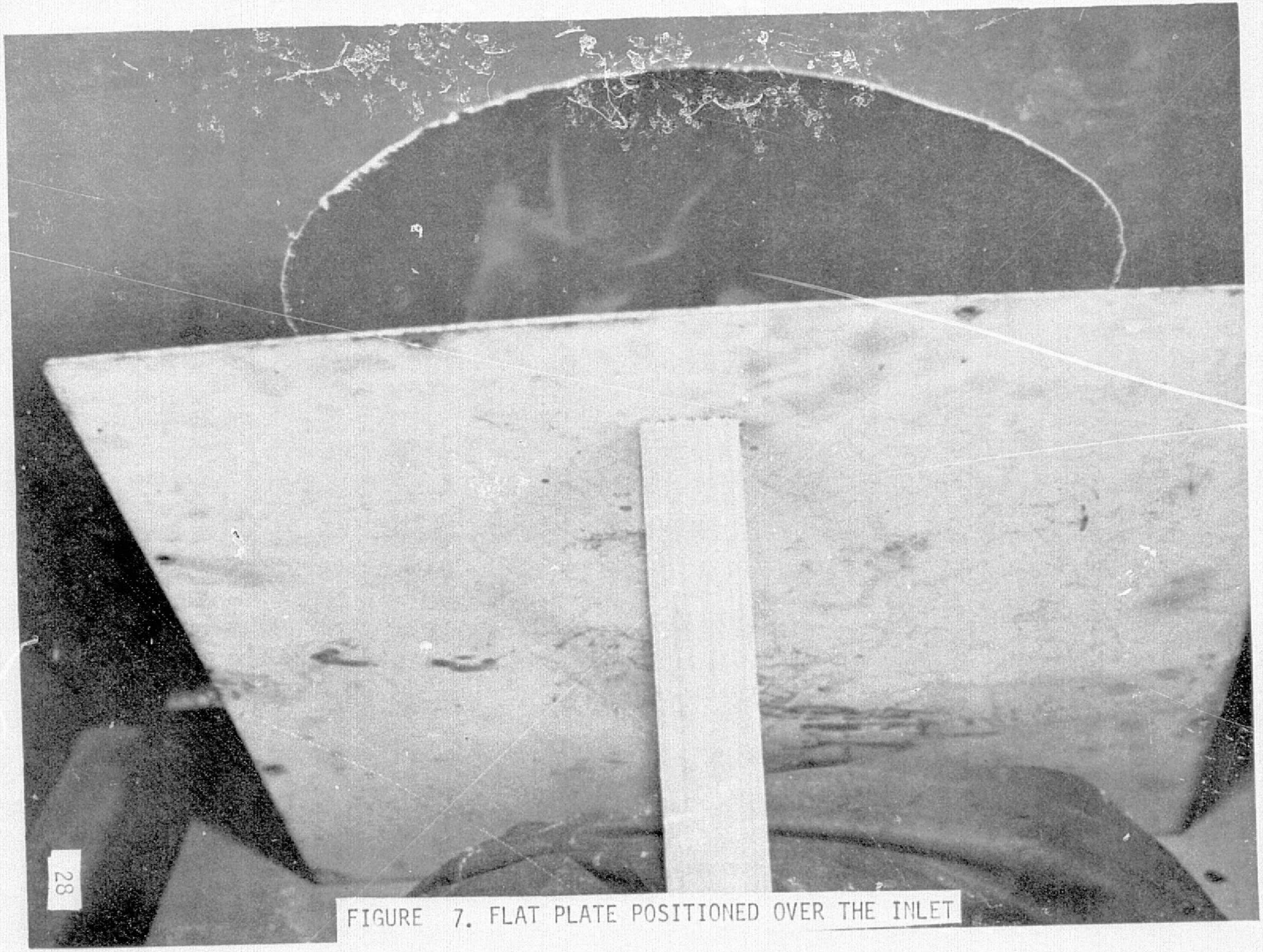
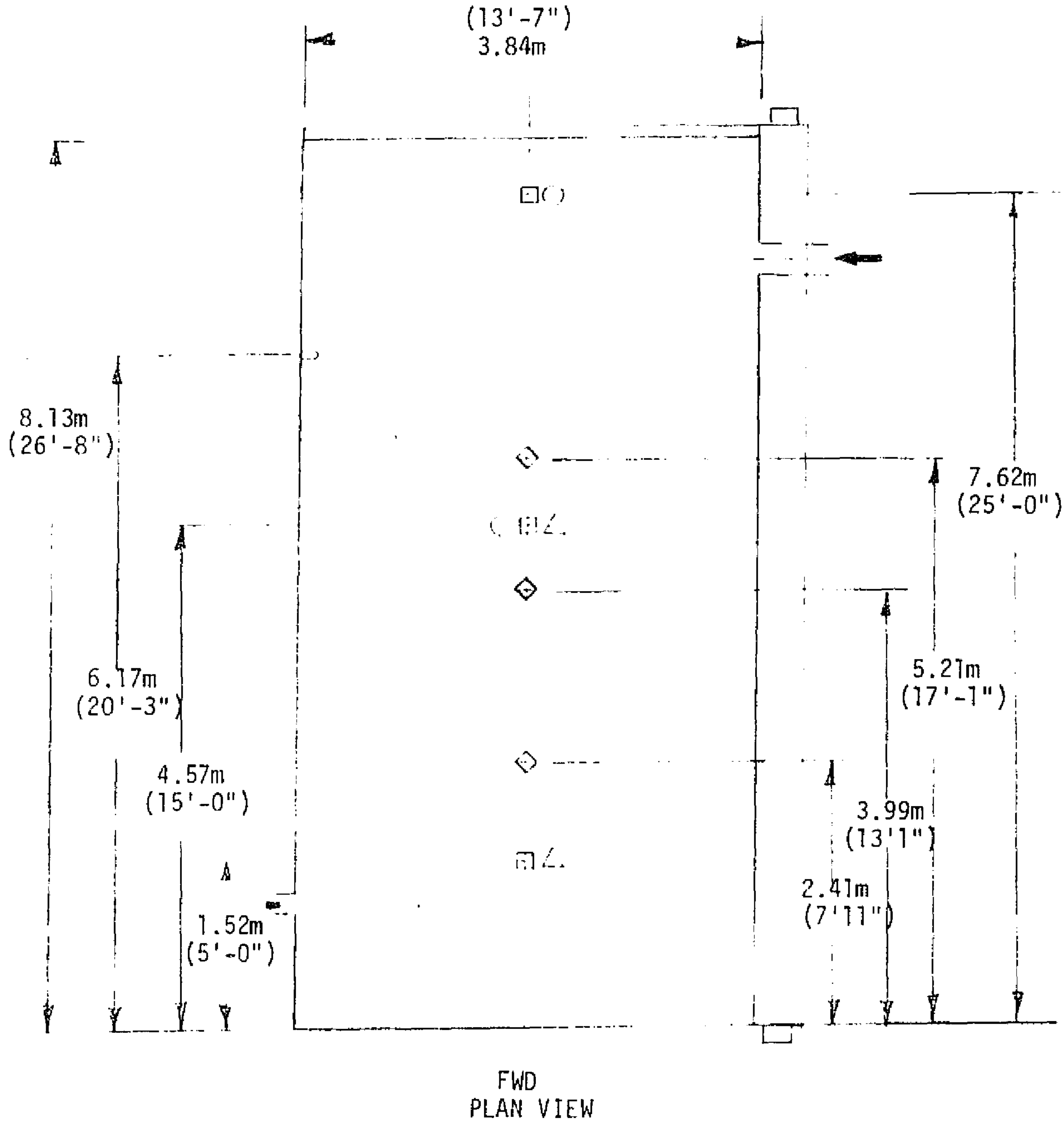


FIGURE 7. FLAT PLATE POSITIONED OVER THE INLET



SMOKE DETECTORS

ULTRAVIOLET INFRARED DETECTORS

ULTRAVIOLET DETECTORS

CALORIMETERS

PRESSURE PICKUP

FIGURE 8. SCHEMATIC OF DETECTORS, CALORIMETERS AND PRESSURE PICKUP - TEST NO. 2

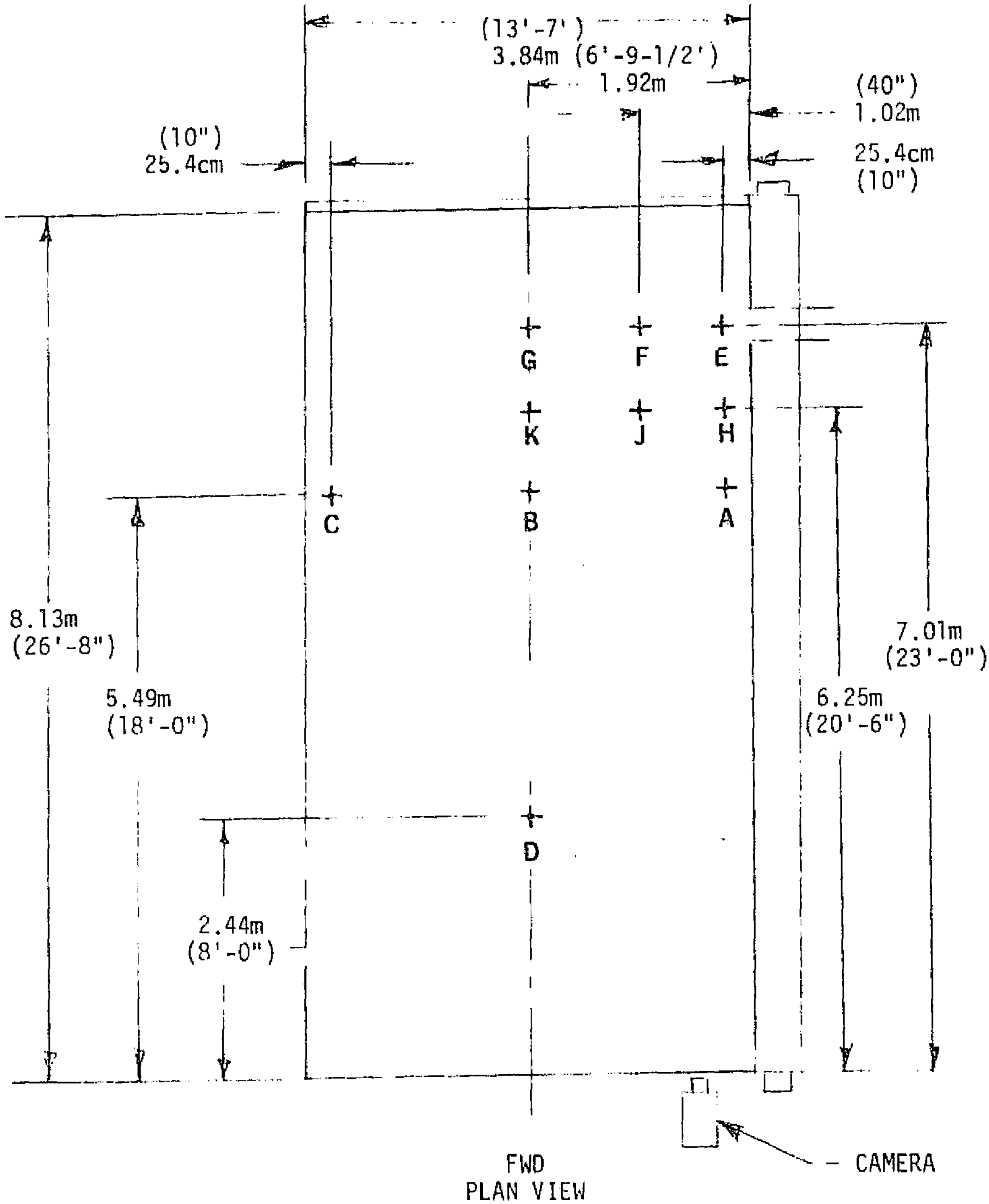
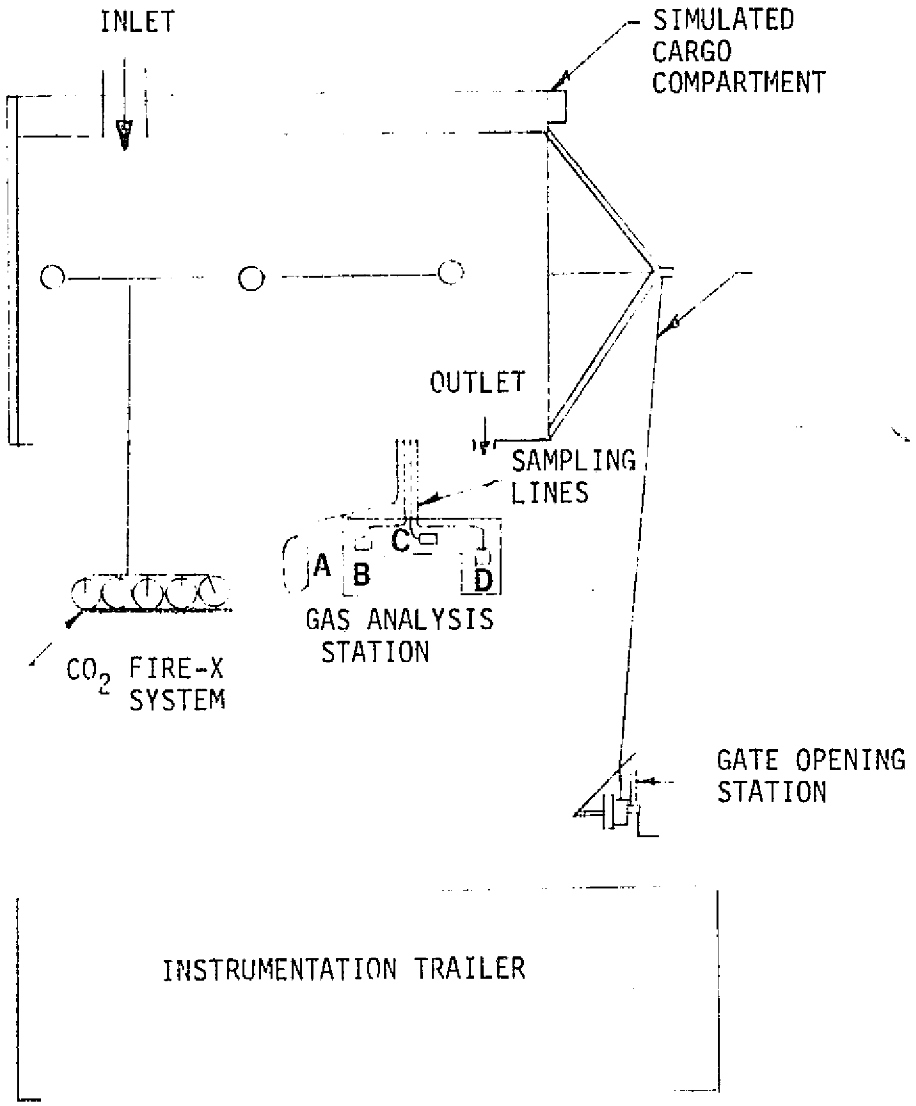


FIGURE 9. SCHEMATIC OF THERMOCOUPLE LOCATION - TEST NO. 2



A = TANK GRAB SAMPLE

B = CARBON MONOXIDE ANALYZER

C = OXYGEN ANALYZER

D = TOTAL HYDROCARBON ANALYZER

FIGURE 10. SIMULATED CARGO COMPARTMENT SHOWING RELATIVE LOCATION OF GAS SAMPLING EQUIPMENT - TEST NO. 1 & TEST NO. 2

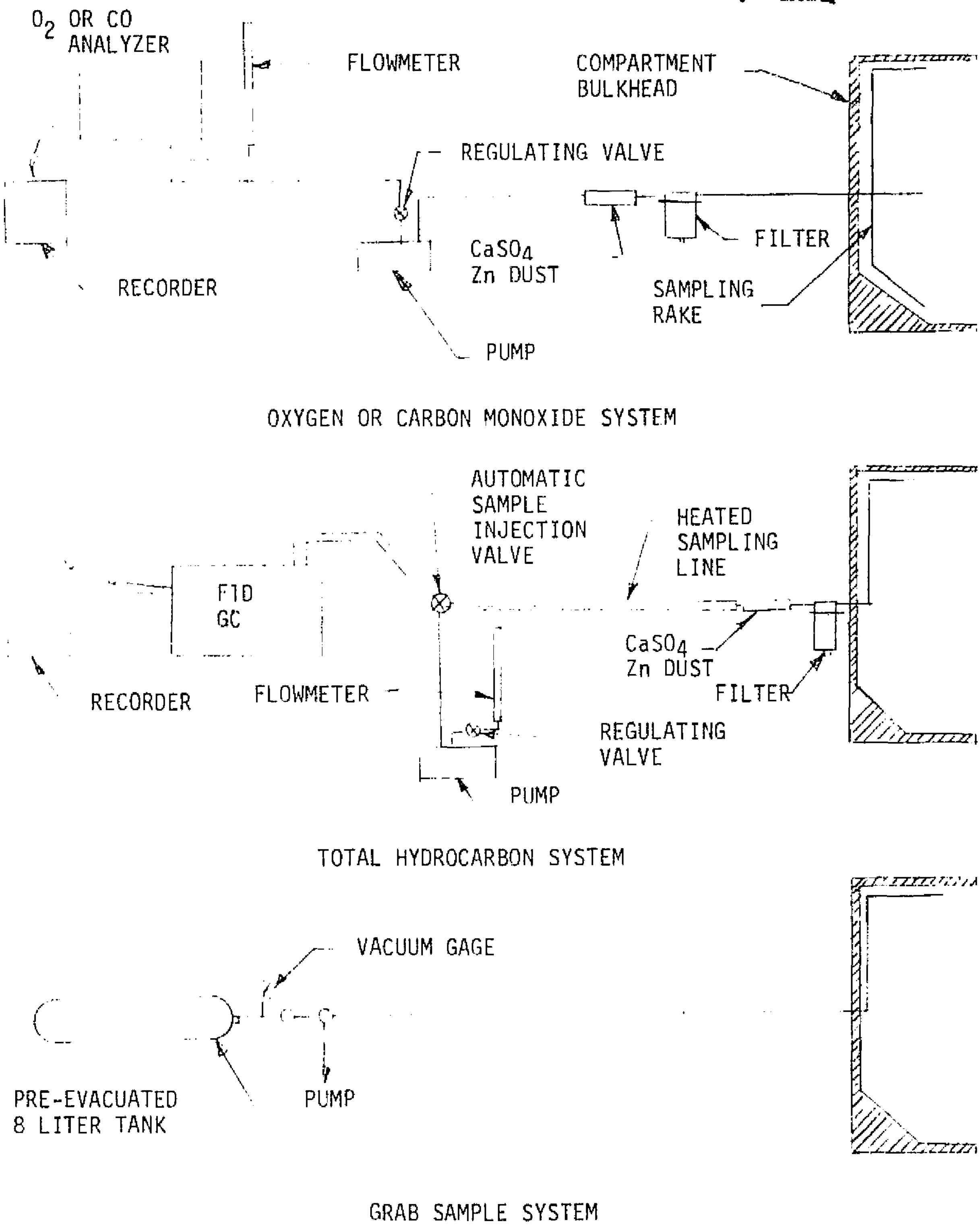


FIGURE 11. SCHEMATICS OF OXYGEN, CARBON MONOXIDE, TOTAL HYDROCARBON AND GRAB SAMPLING SYSTEMS - TEST NO. 2 (TEST NO. 1 SIMILAR)

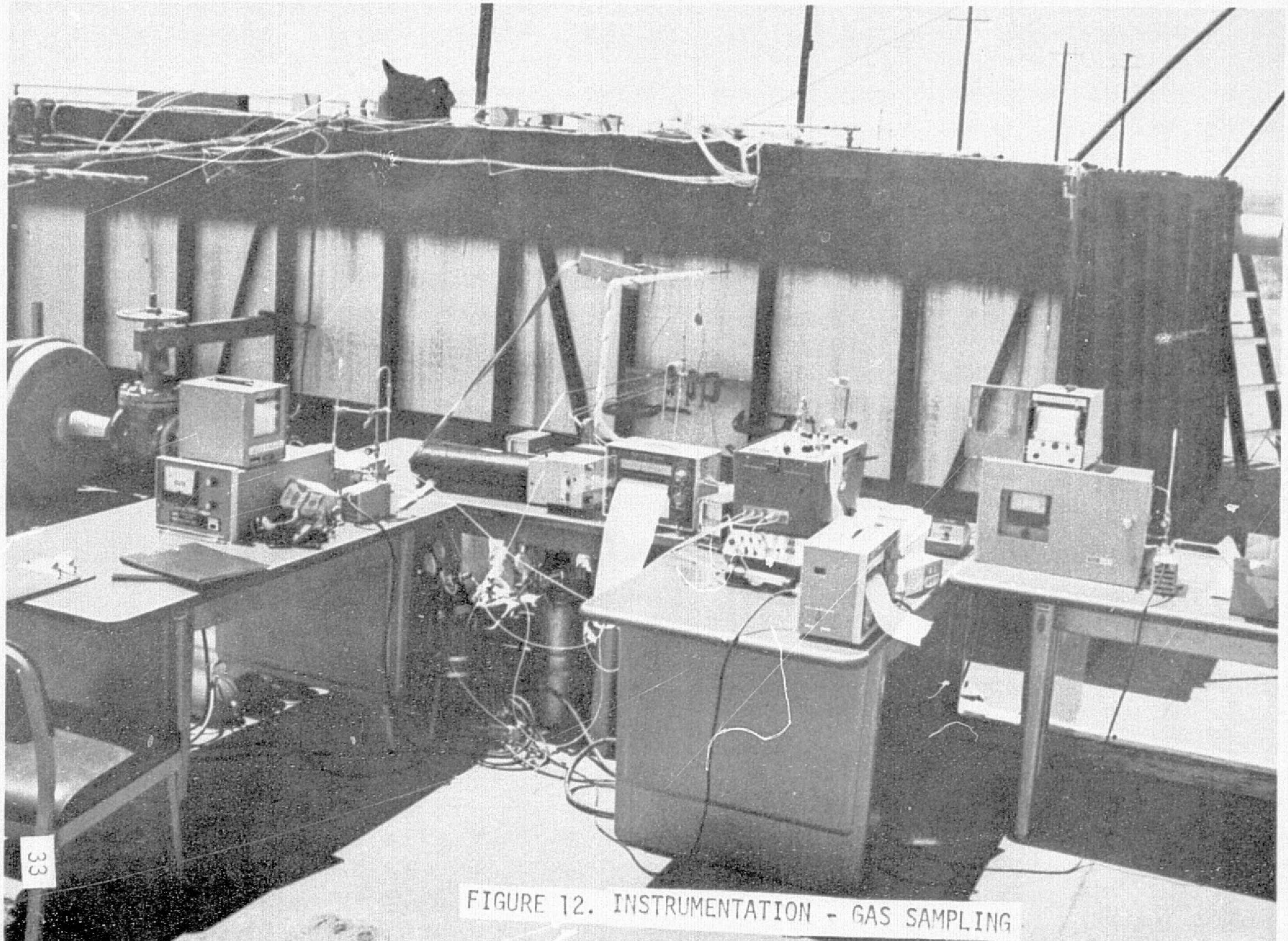


FIGURE 12. INSTRUMENTATION - GAS SAMPLING

STRUCTURE THERMOCOUPLE

POSITION 'B'

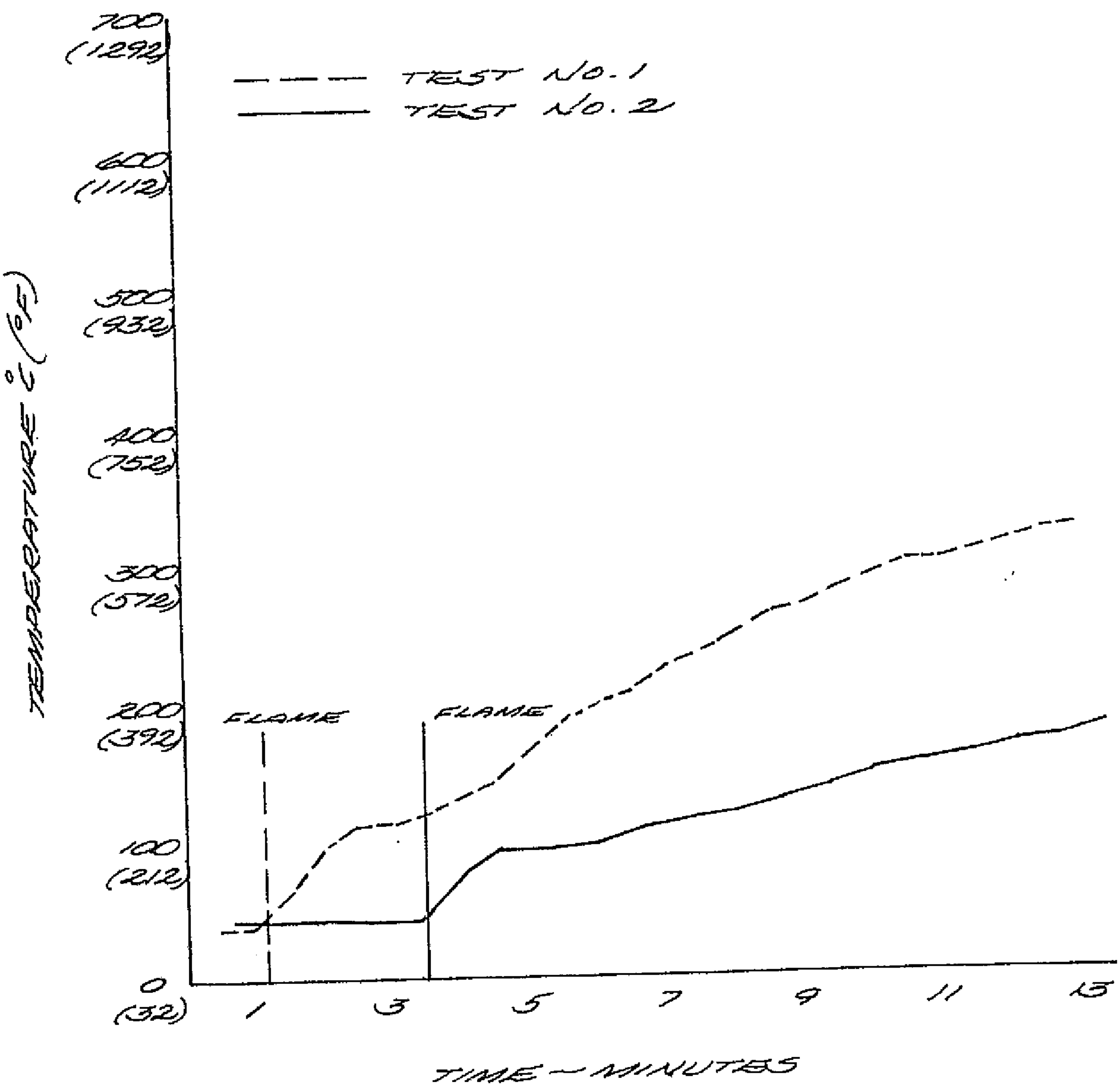


FIGURE 13 COMPARISON - STRUCTURE TEMPERATURE, POSITION B

3A

ORIGINAL PAGE IS
OF POOR QUALITY

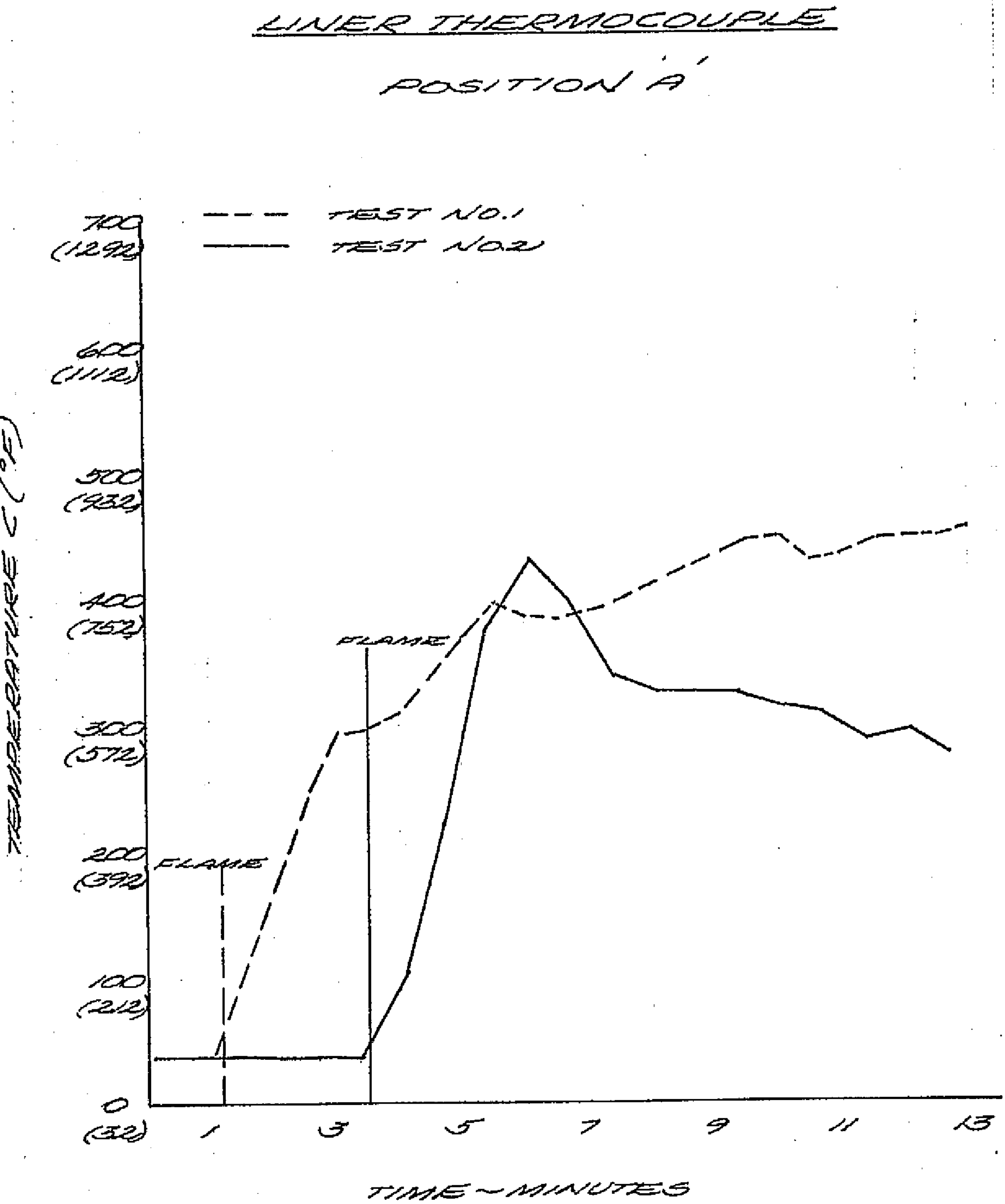


FIGURE 14 COMPARISON - LINER TEMPERATURE, POSITION A

AIR THERMOCOUPLE

POSITION 'A'

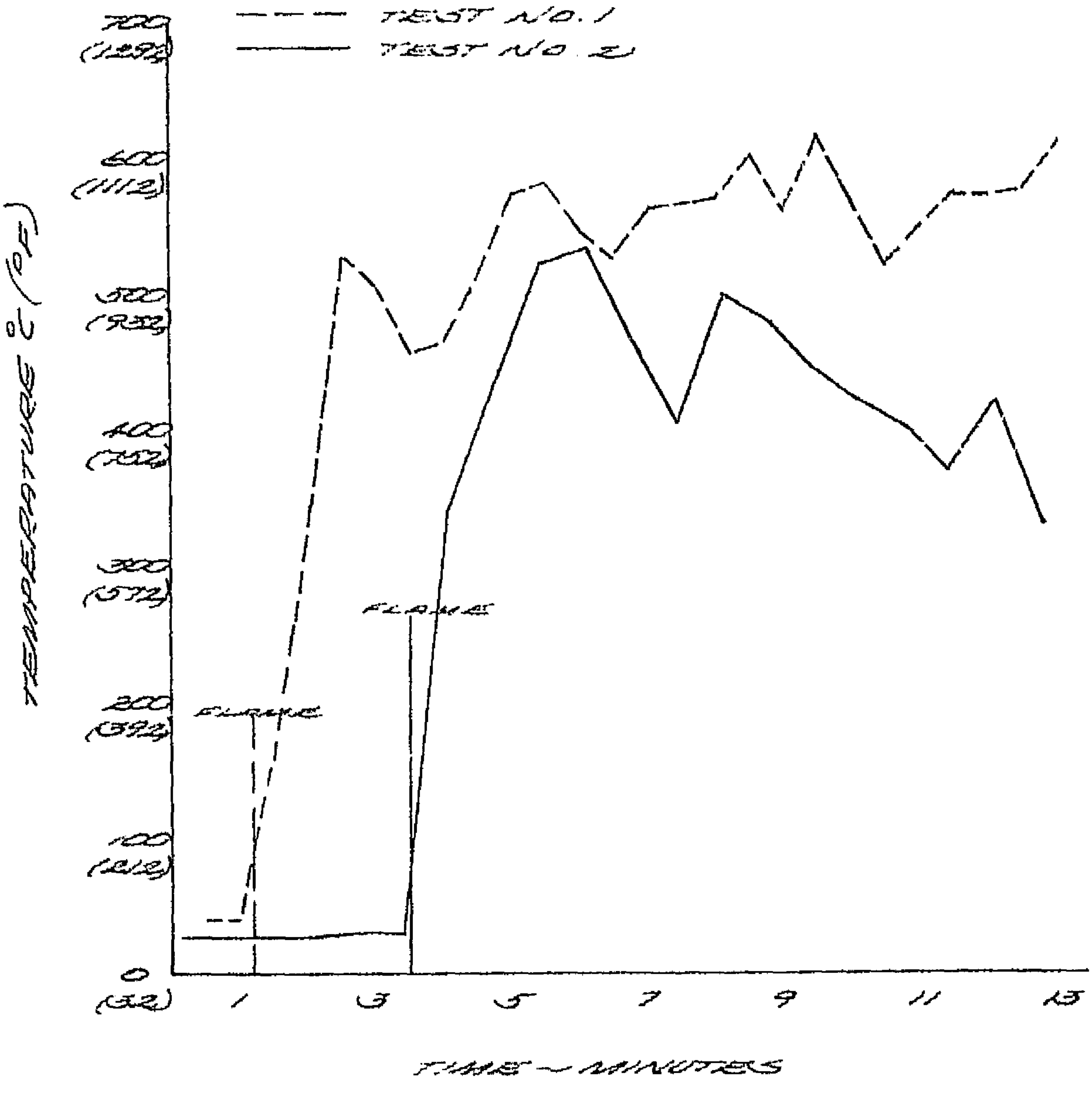


FIGURE 15 COMPARISON AIR TEMPERATURE, POSITION A

AIR THERMOCOUPLE

POSITION 'B'

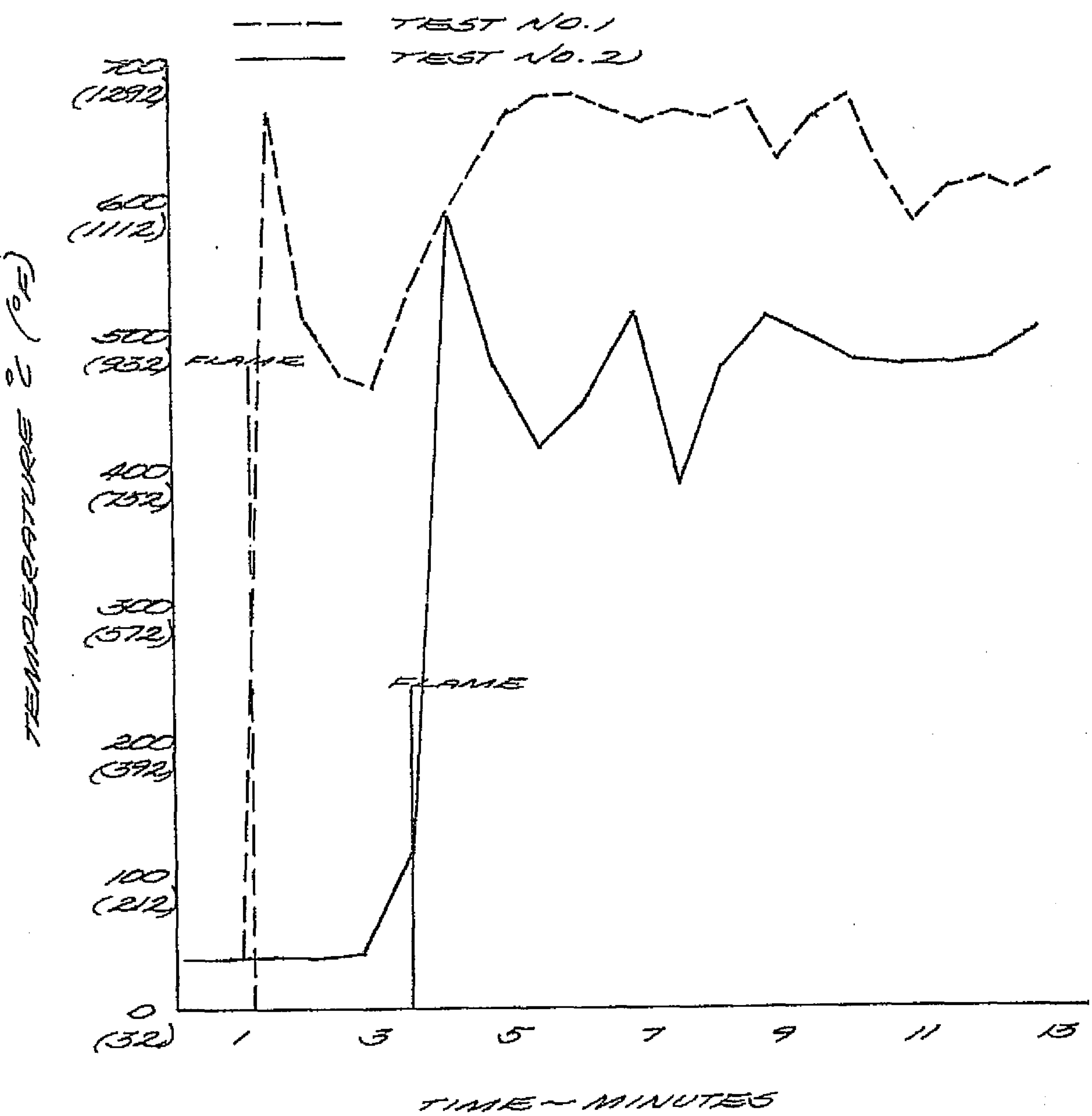


FIGURE 16 COMPARISON AIR TEMPERATURE, POSITION B

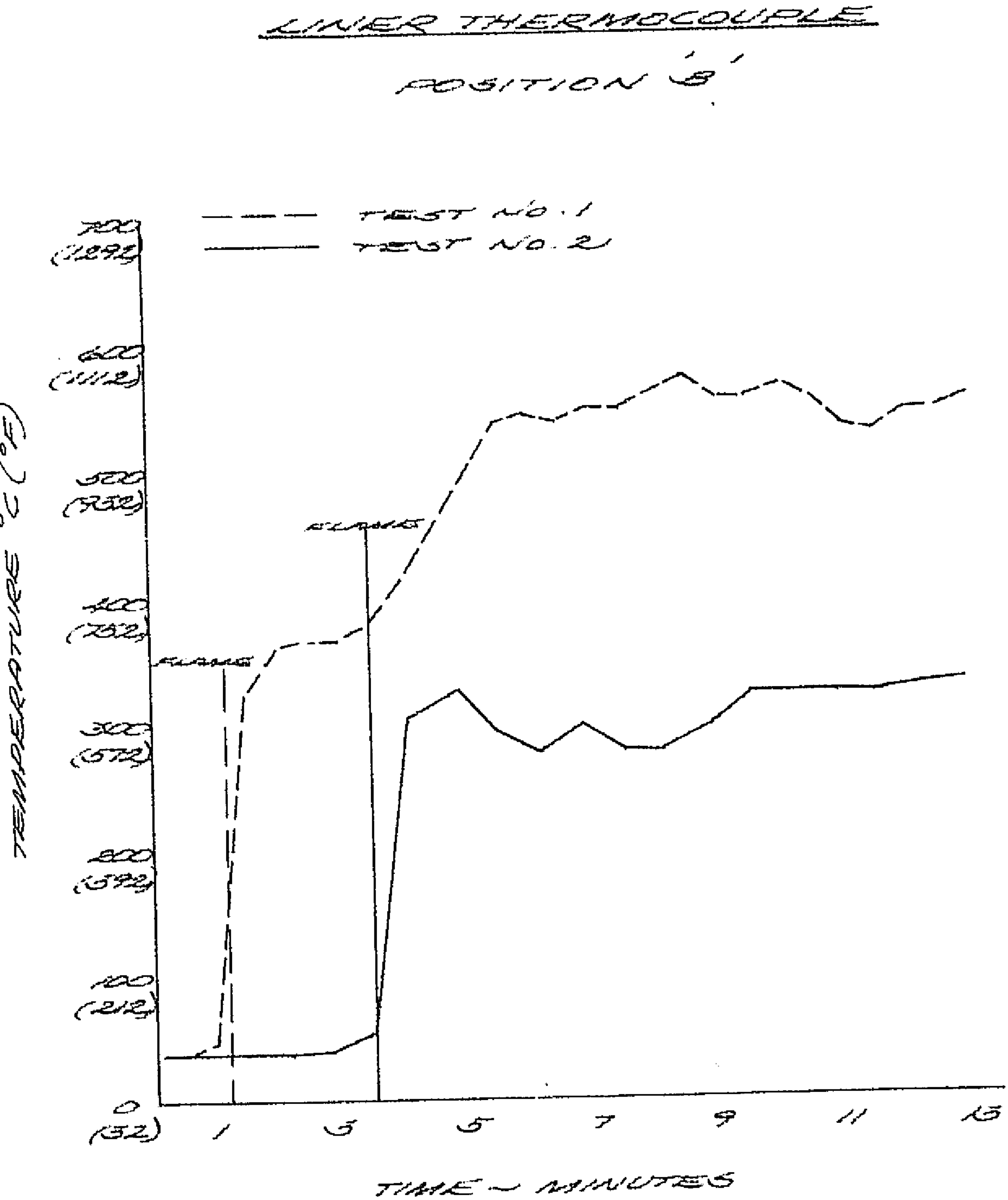


FIGURE 17 COMPARISON LINER TEMPERATURE, POSITION B

LINER THERMOCOUPLE

POSITION 'C'

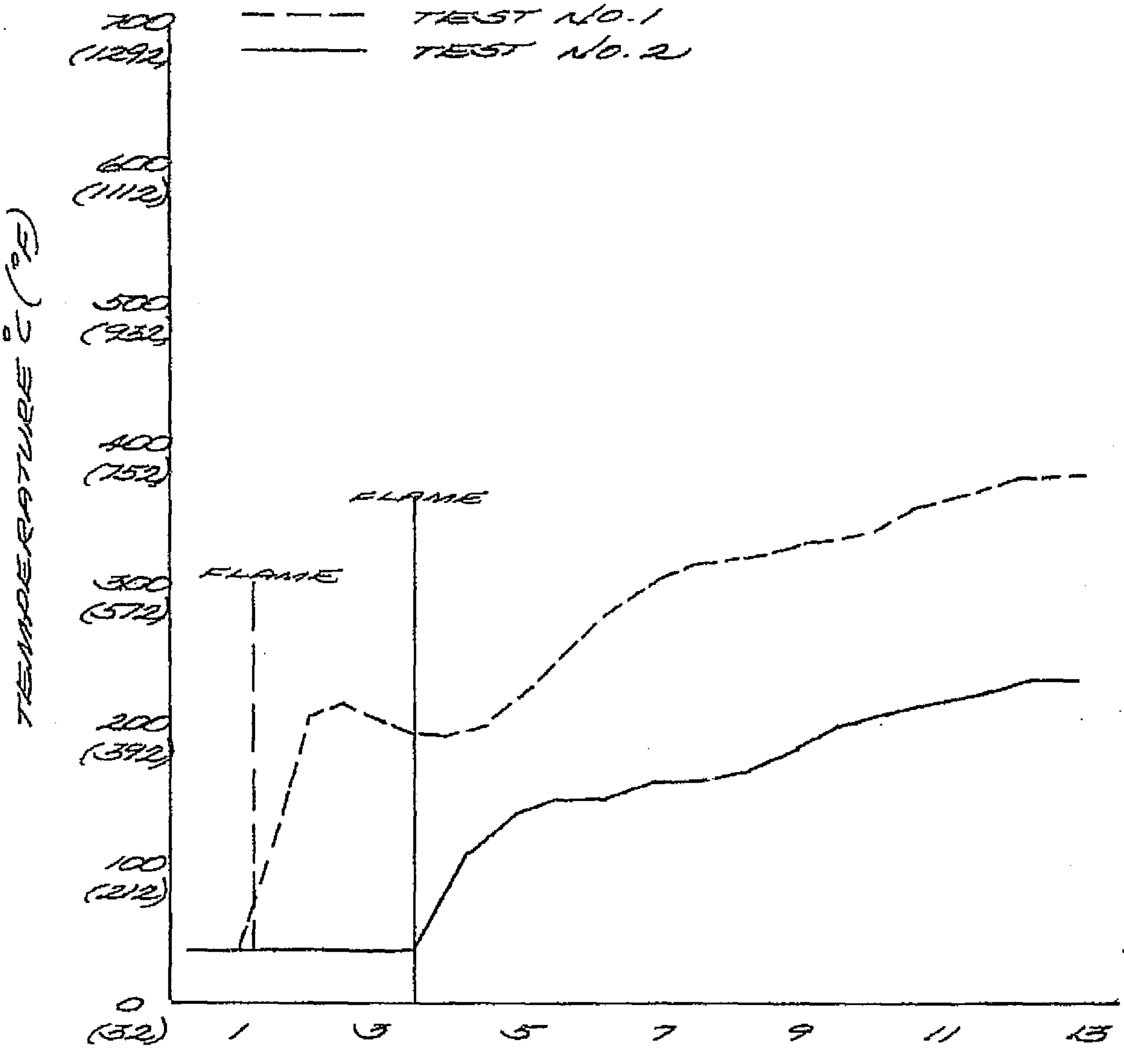


FIGURE 18 COMPARISON LINER TEMPERATURE, POSITION C

AIR THERMOCOUPLE

POSITION 'C'

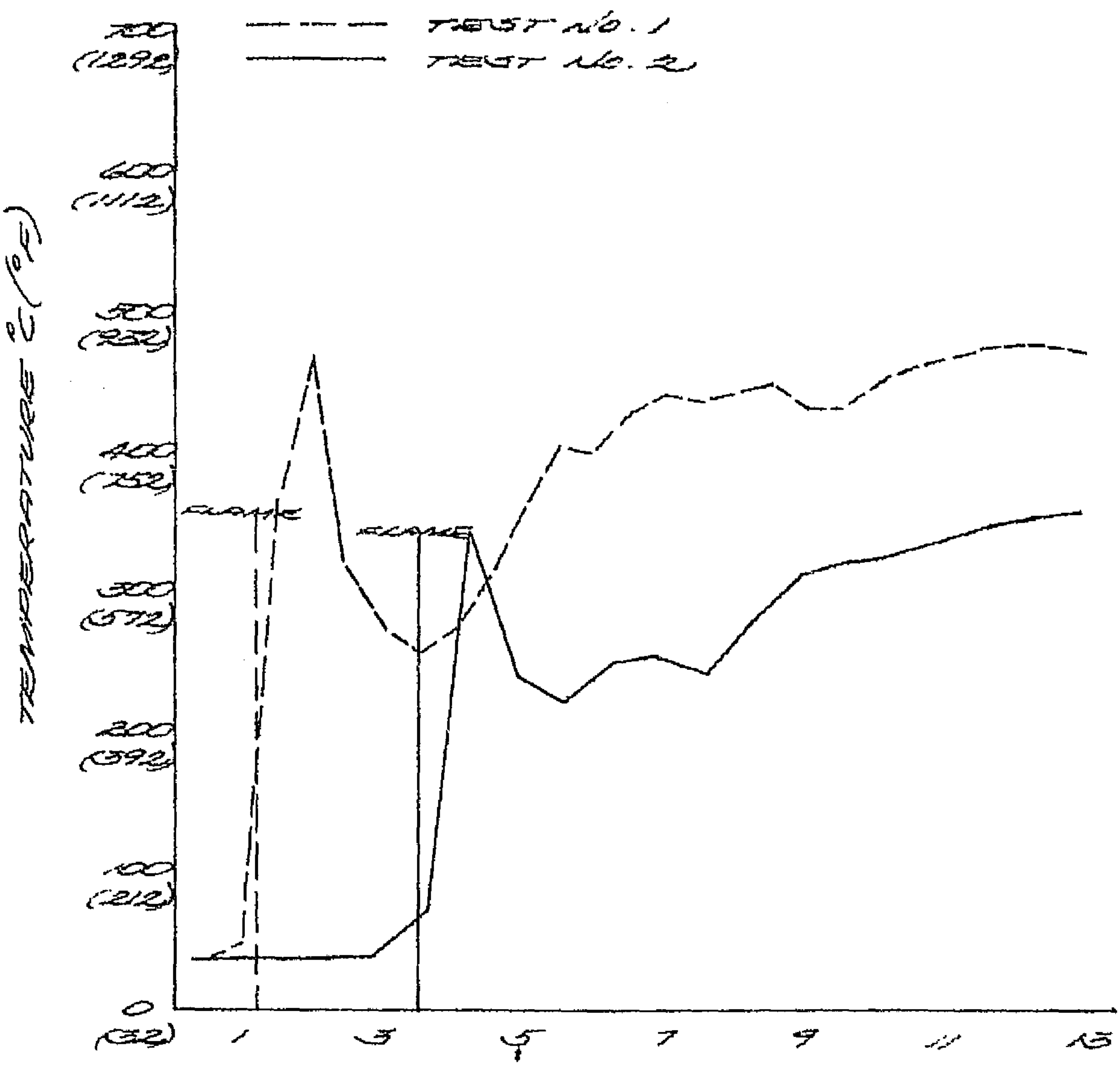


FIGURE 19 COMPARISON AIR TEMPERATURE, POSITION C

LINER THERMOCOUPLE

POSITION 'D'

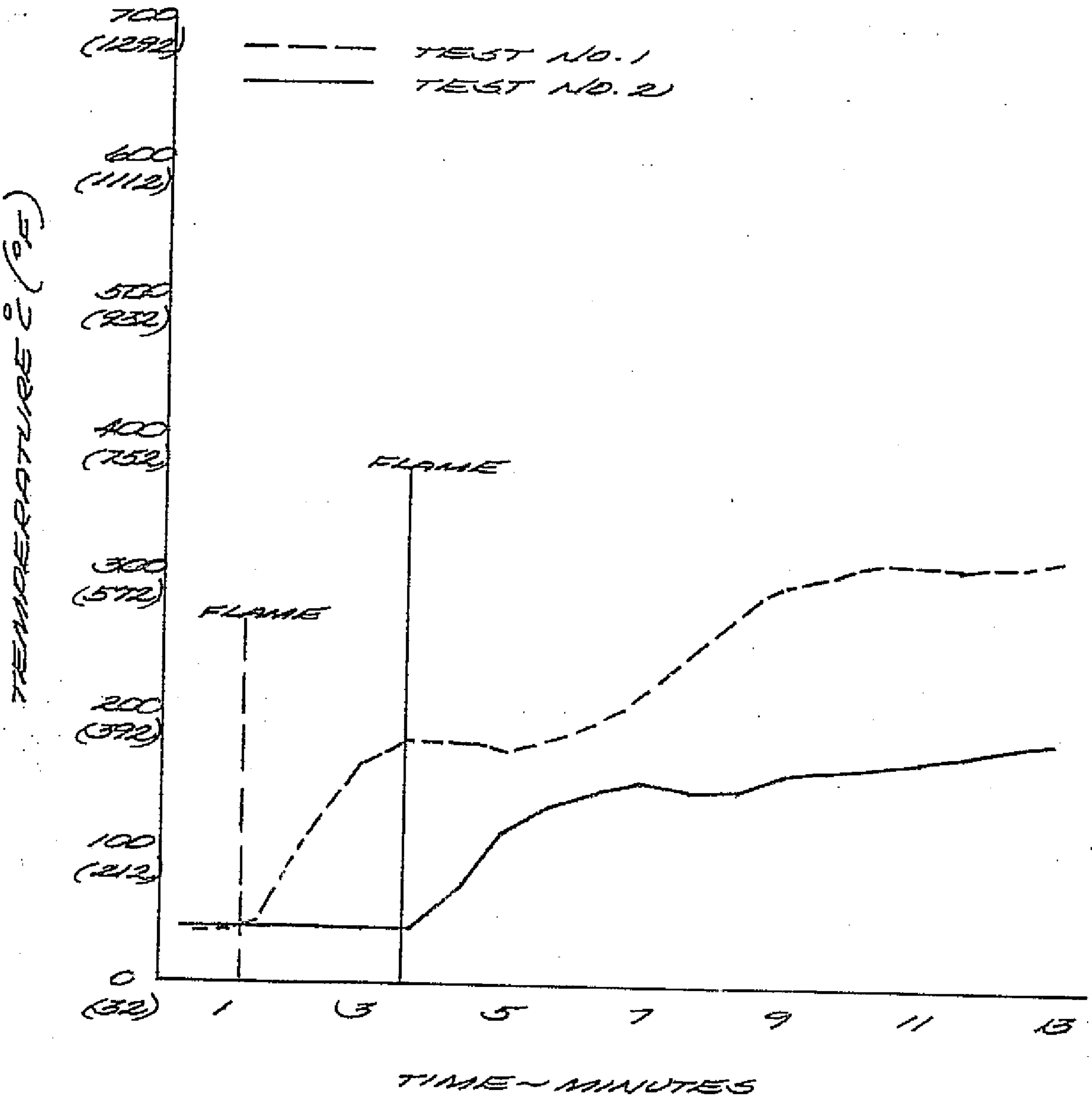


FIGURE 20 COMPARISON LINER
TEMPERATURE, POSITION D

AIR THERMOCOUPLE

POSITION 'D'

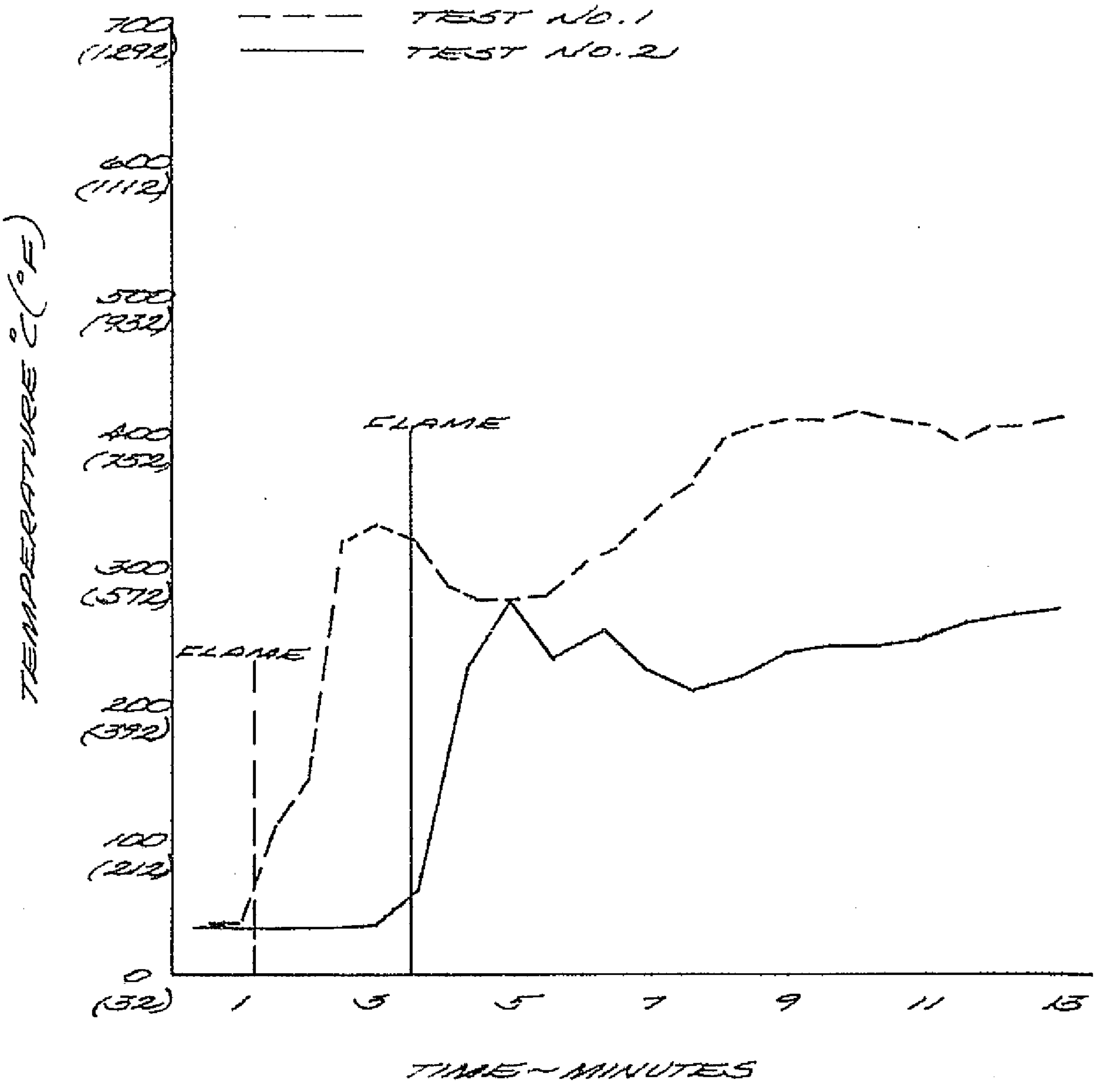


FIGURE 21 COMPARISON AIR TEMPERATURE, POSITION D

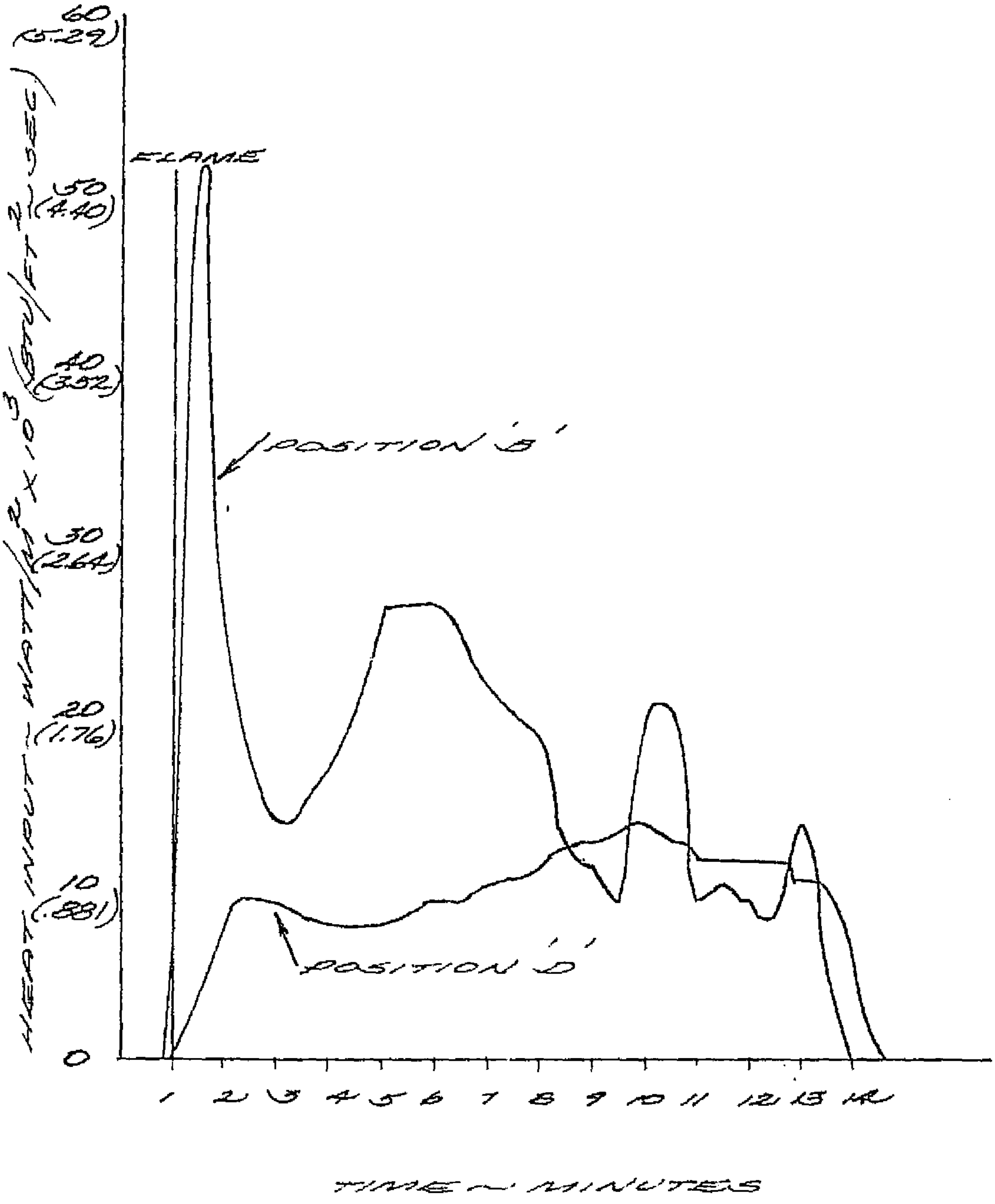


FIGURE 22 HEAT FLUX ~ TEST NO. 1

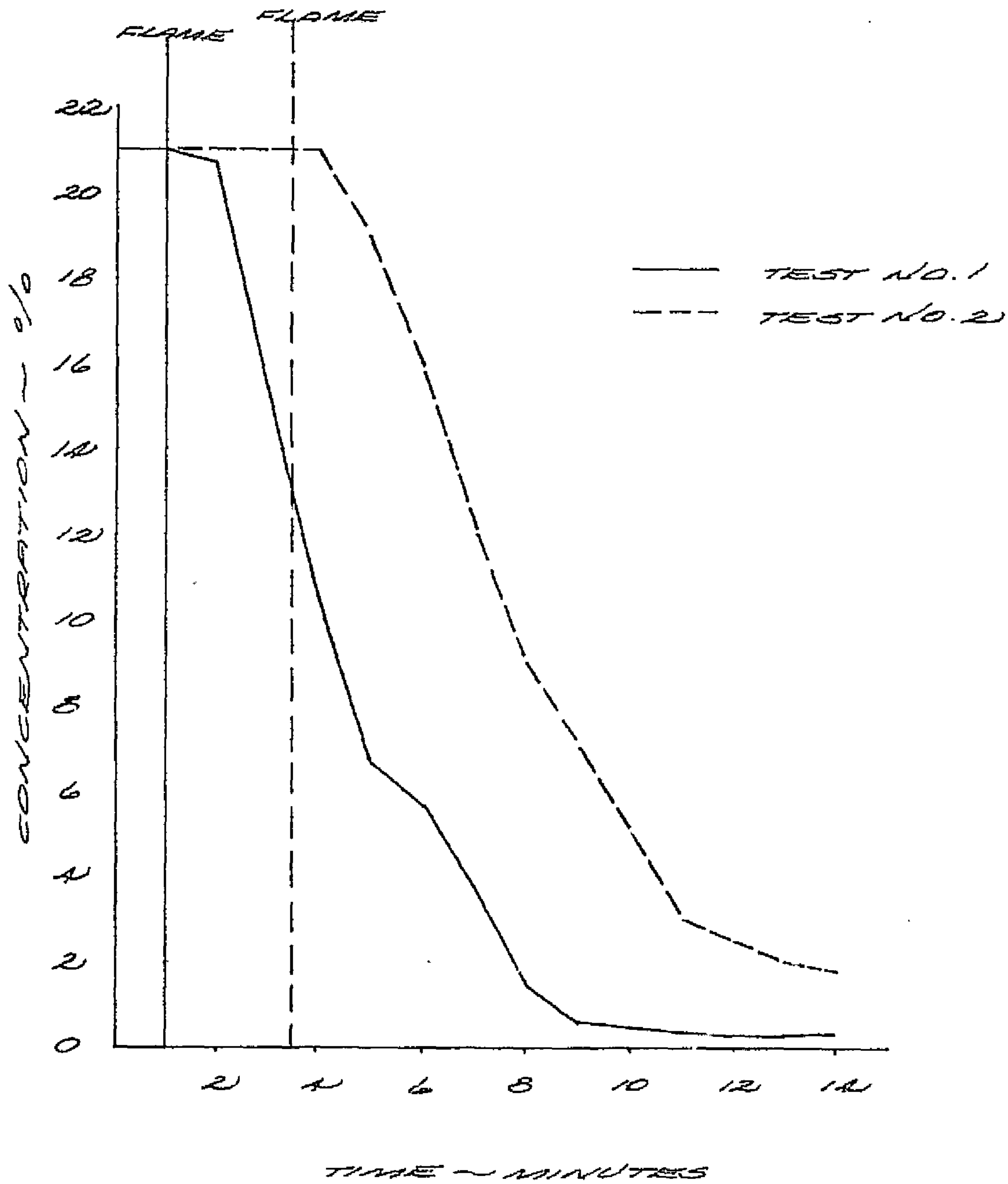


FIGURE 23 COMPARISON - OXYGEN CONCENTRATIONS

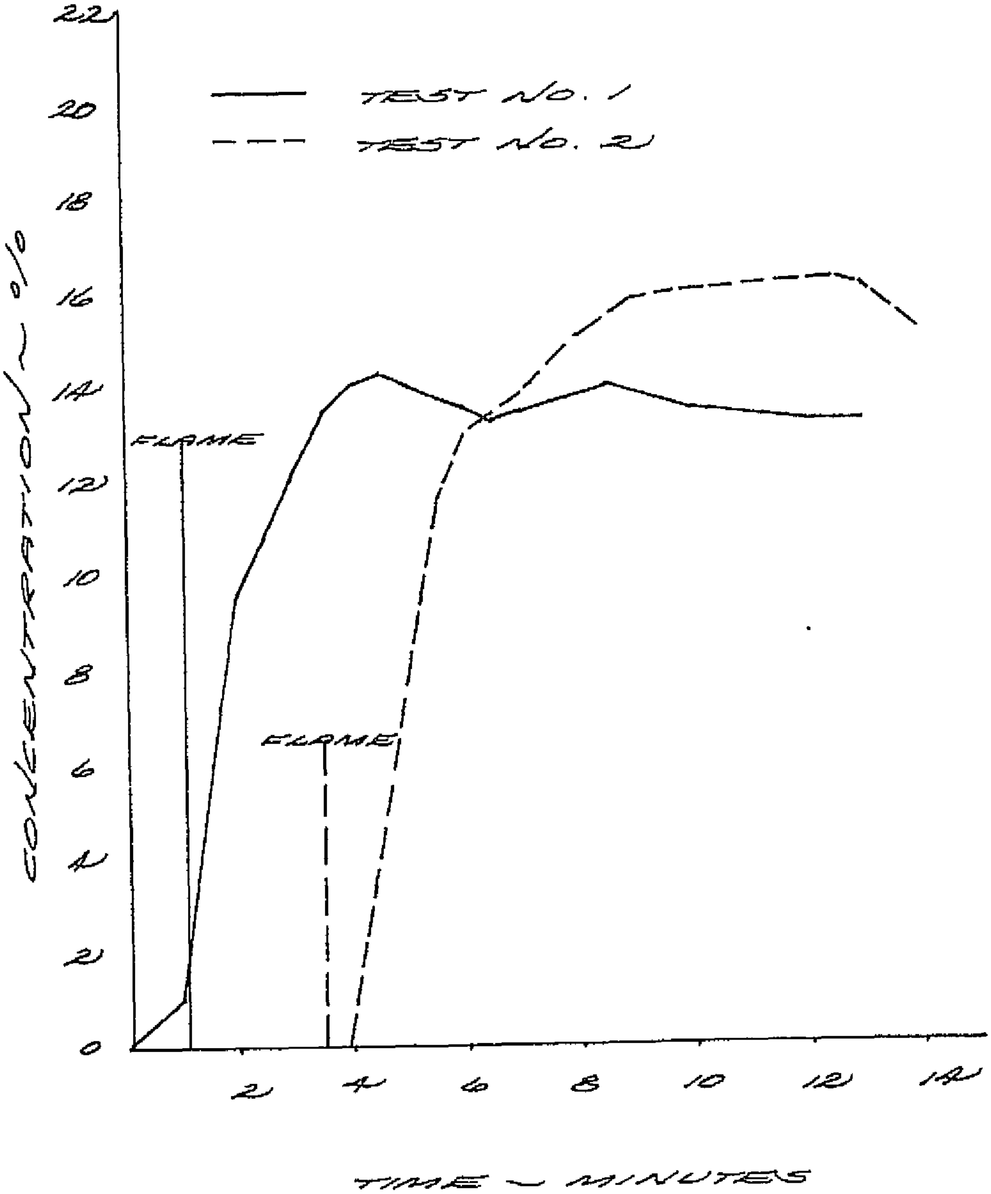


FIGURE 2A COMPARISON CARBON DIOXIDE CONCENTRATIONS

ORIGINAL PAGE IS
OF POOR QUALITY

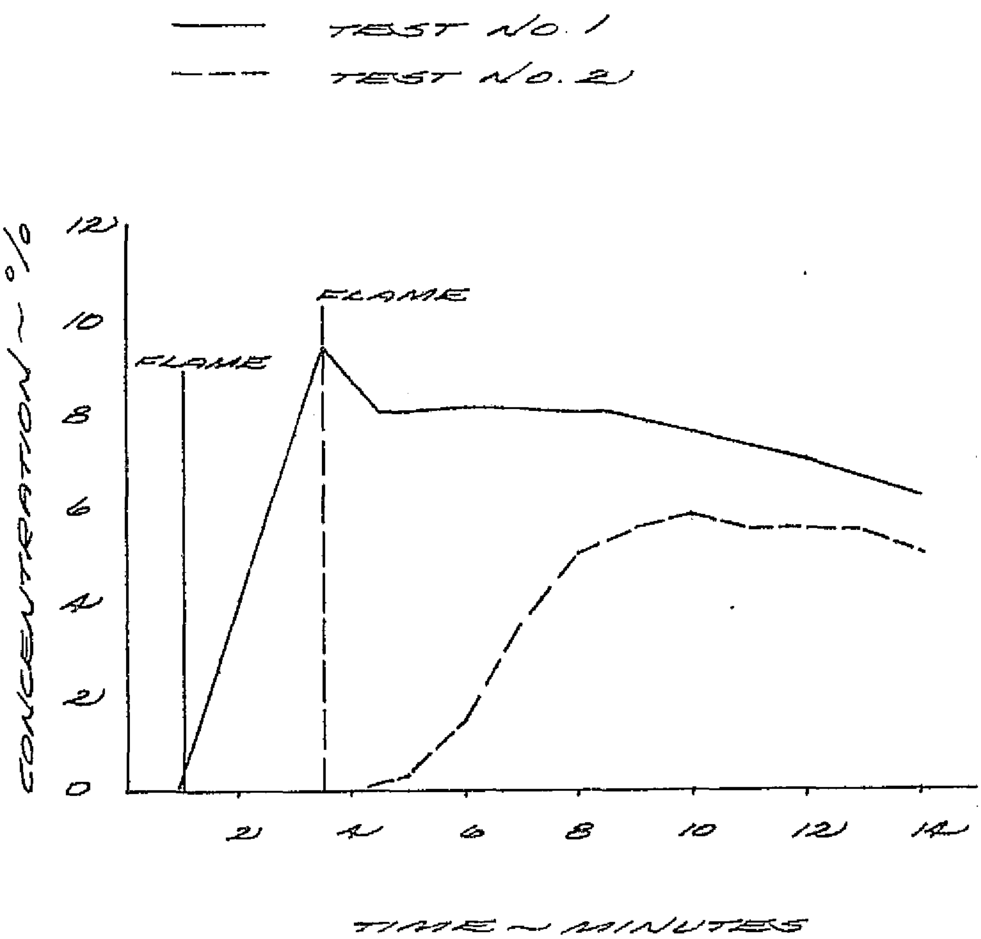


FIGURE 25 COMPARISON CARBON MONOXIDE CONCENTRATIONS

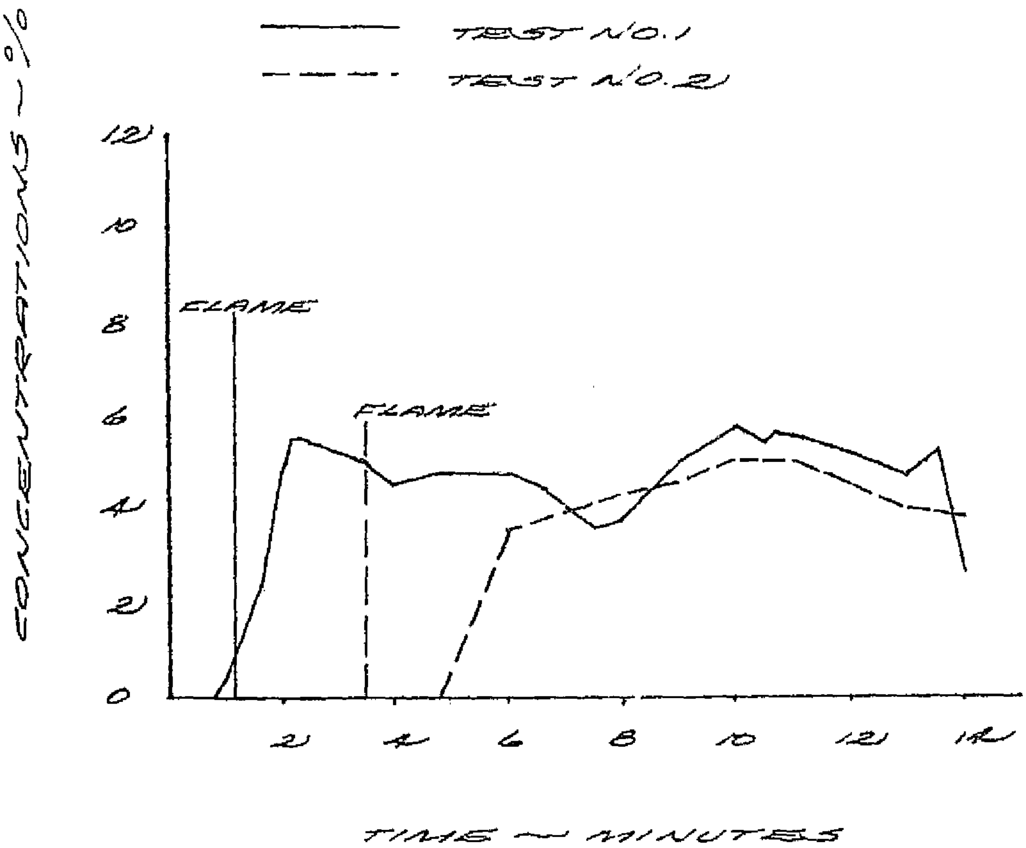


FIGURE 26 COMPARISON TOTAL
HYDROCARBONS
CONCENTRATIONS

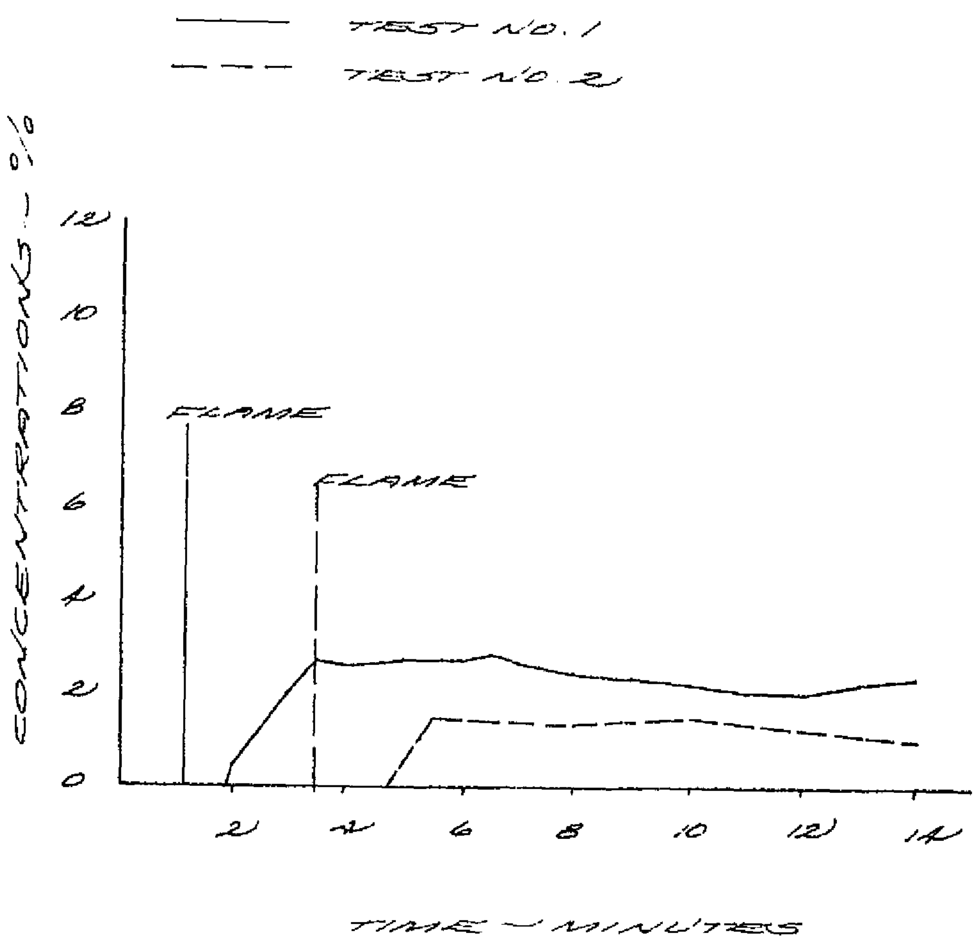


FIGURE 27. COMPARISON- METHANE CONCENTRATIONS

FIGURE 28. CEILING LINER DAMAGE - AREA A
TEST NO. 1

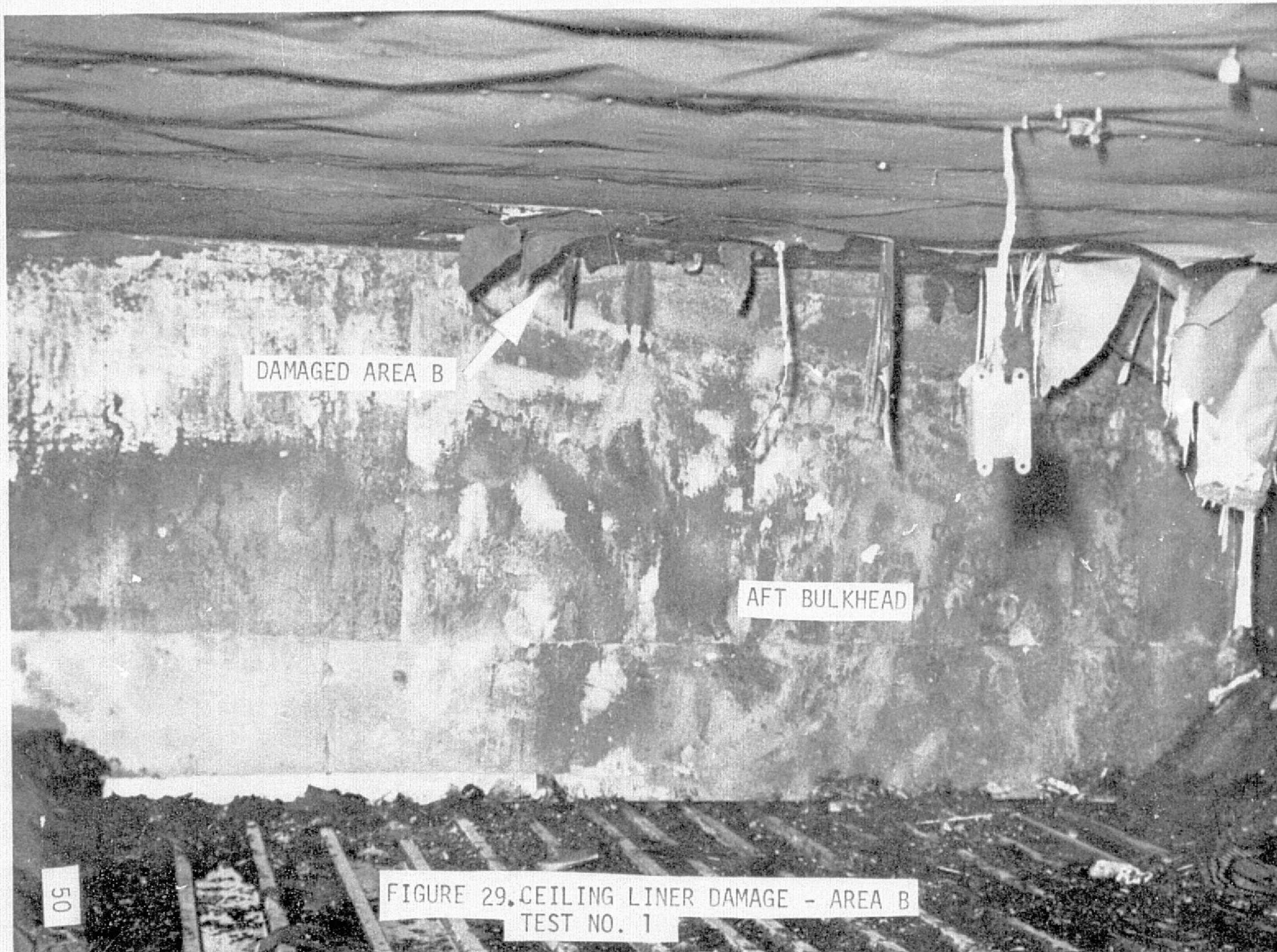


FIGURE 29. CEILING LINER DAMAGE - AREA B
TEST NO. 1

ORIGINAL PAGE IS
OF POOR QUALITY

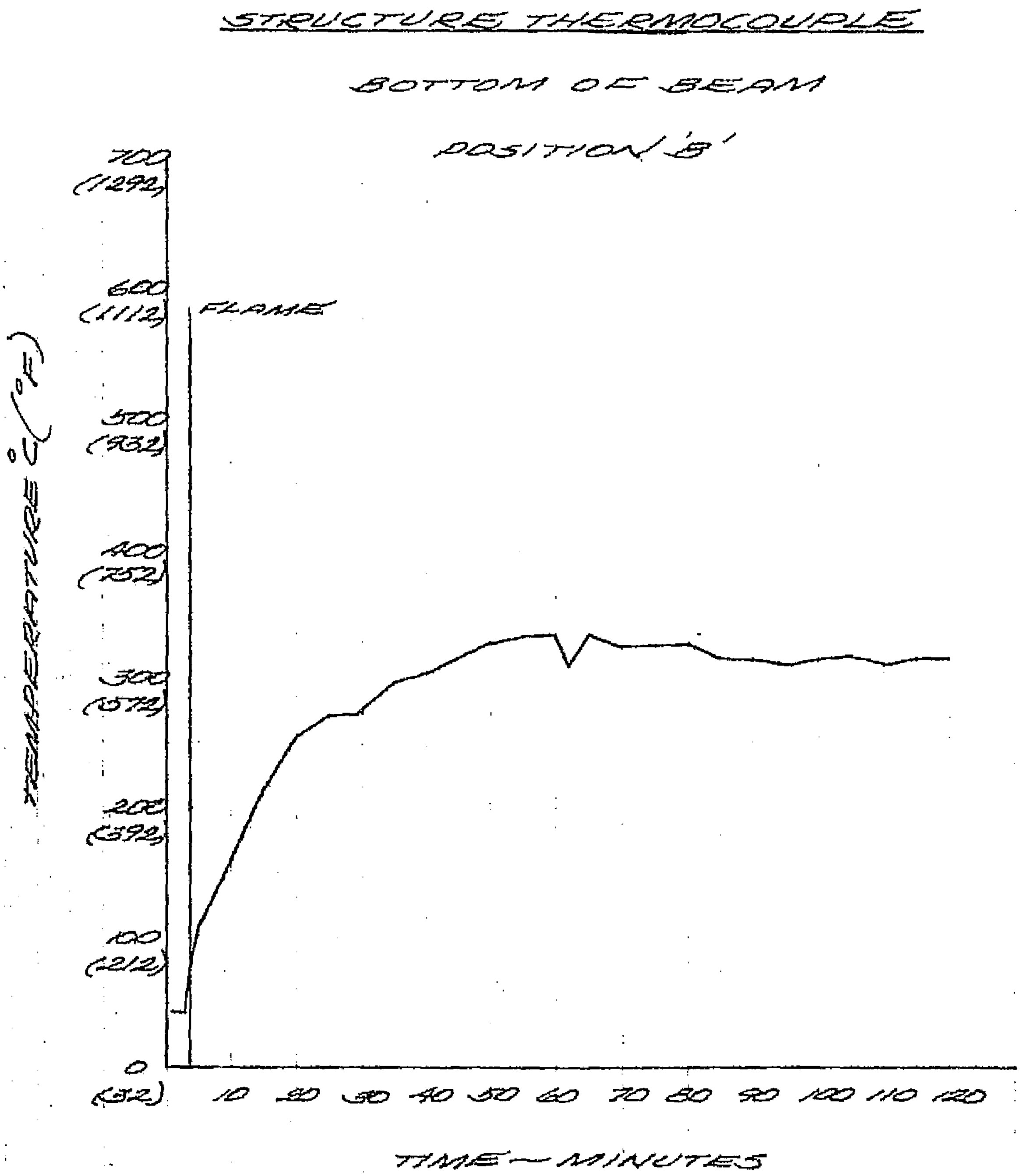


FIGURE 30 STRUCTURE TEMPERATURE, BOTTOM OF BEAM, POSITION B - TEST NO. 2

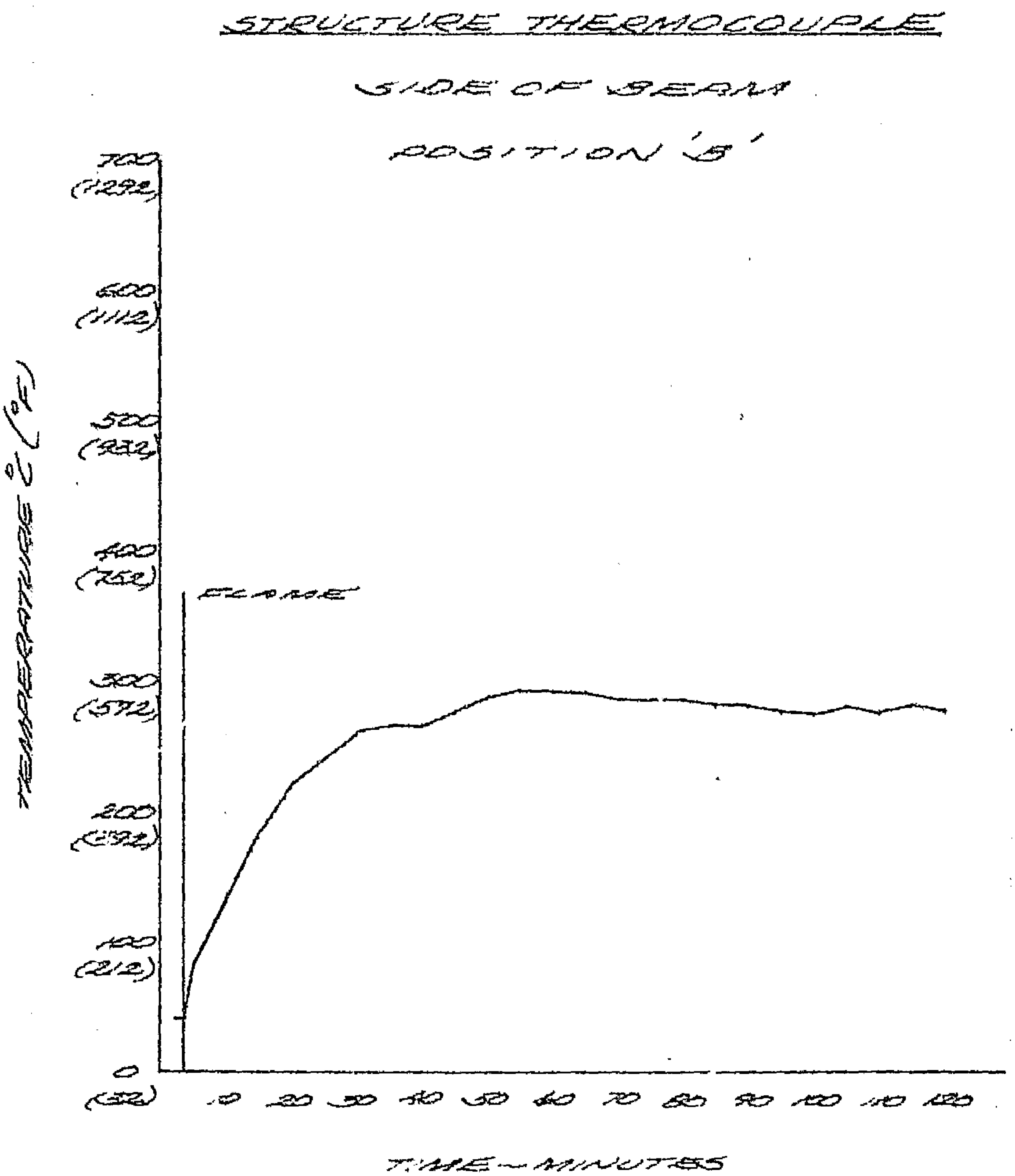


FIGURE 31 STRUCTURE TEMPERATURE, SIDE OF BEAM, POSITION 8 - TEST NO. 2

LINER THERMOCOUPLE

POSITION 'A'

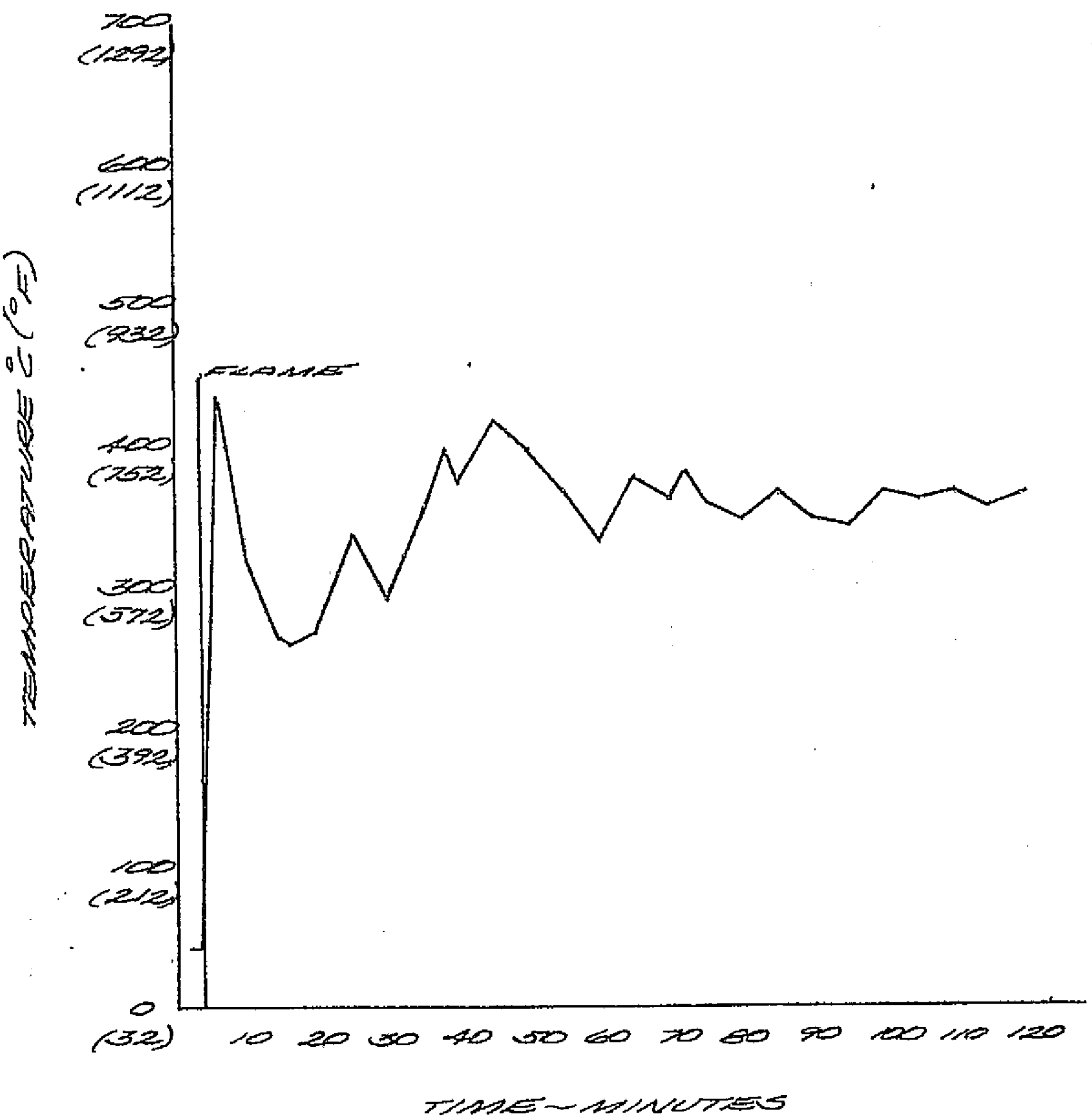


FIGURE 32 LINER TEMPERATURE, POSITION A, TEST NO. 2)

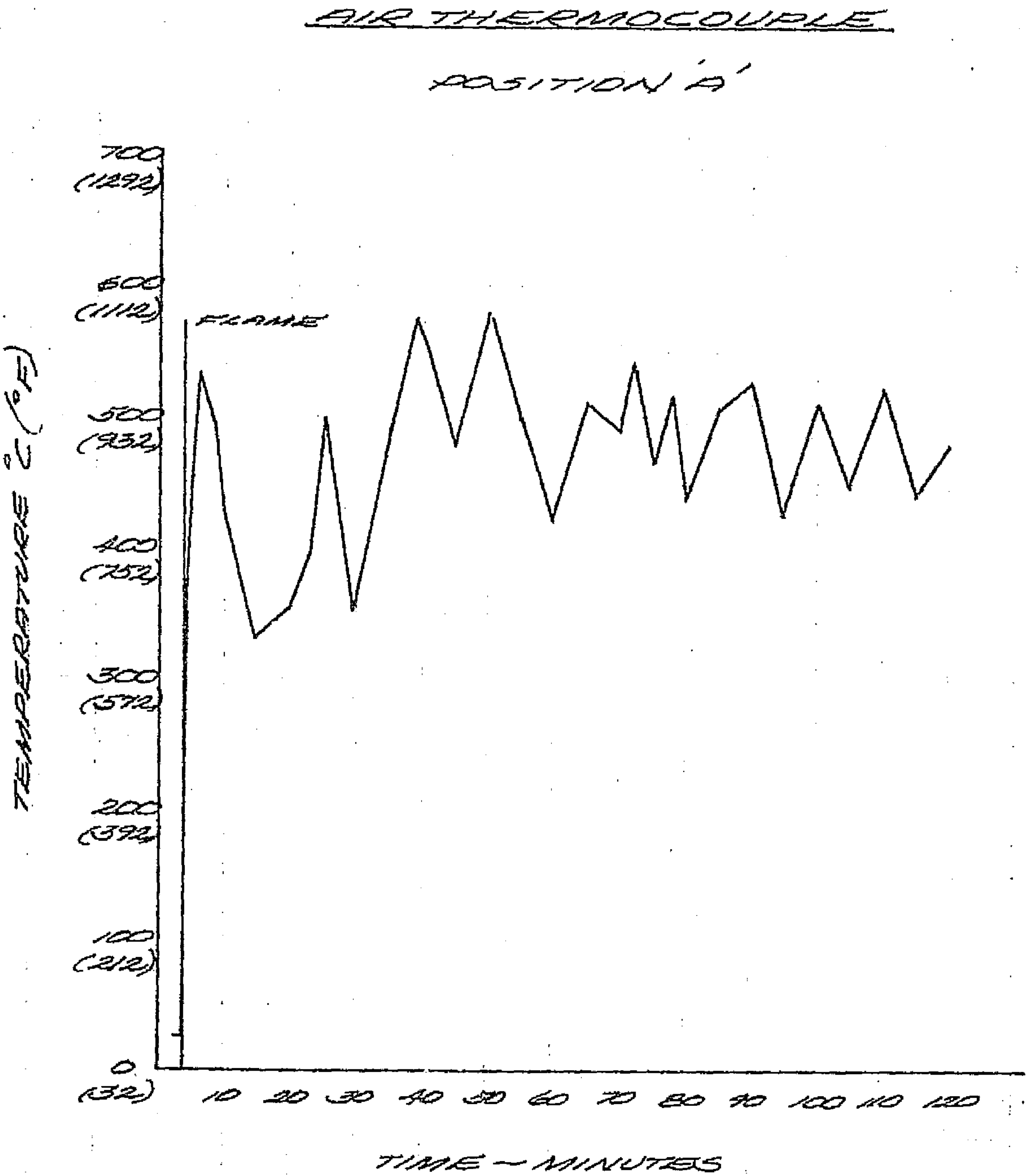


FIGURE 33. AIR TEMPERATURE, POSITION A - TEST NO. 2)

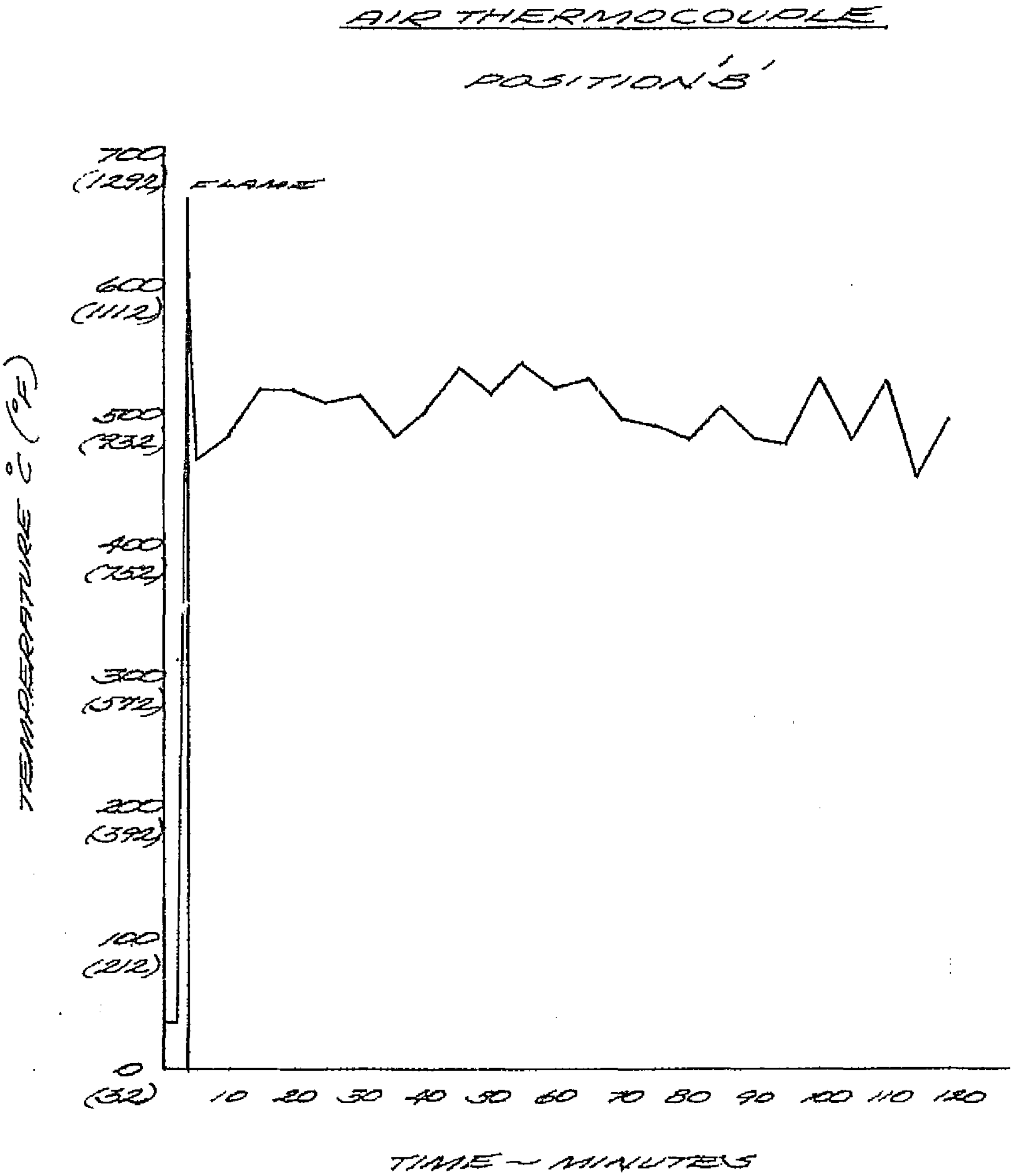


FIGURE 34 AIR TEMPERATURE, POSITION B - TEST NO. 2

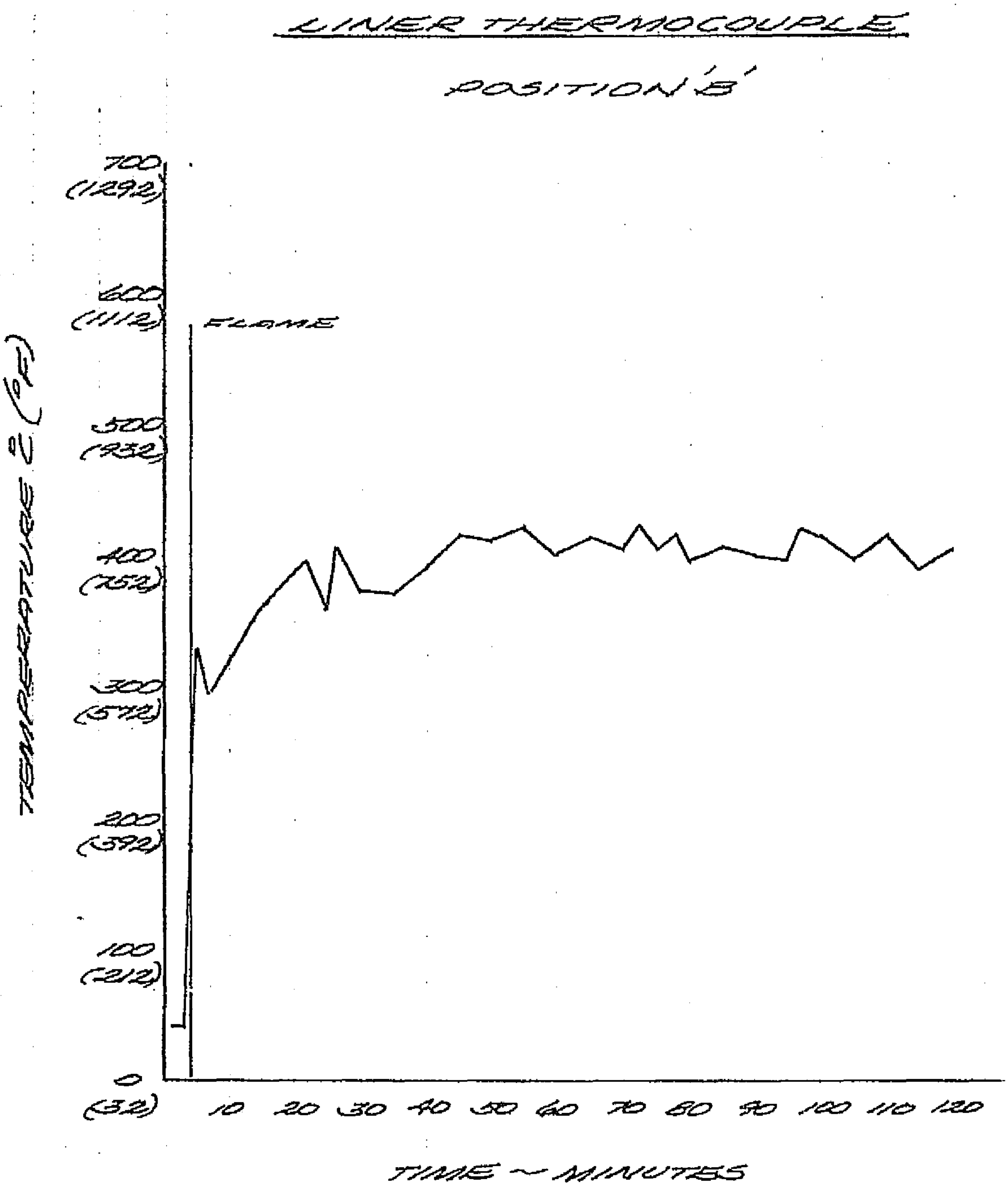


FIGURE 35 LINER TEMPERATURE, POSITION B - TEST NO. 2)

ORIGINAL PAGE IS
OF POOR QUALITY

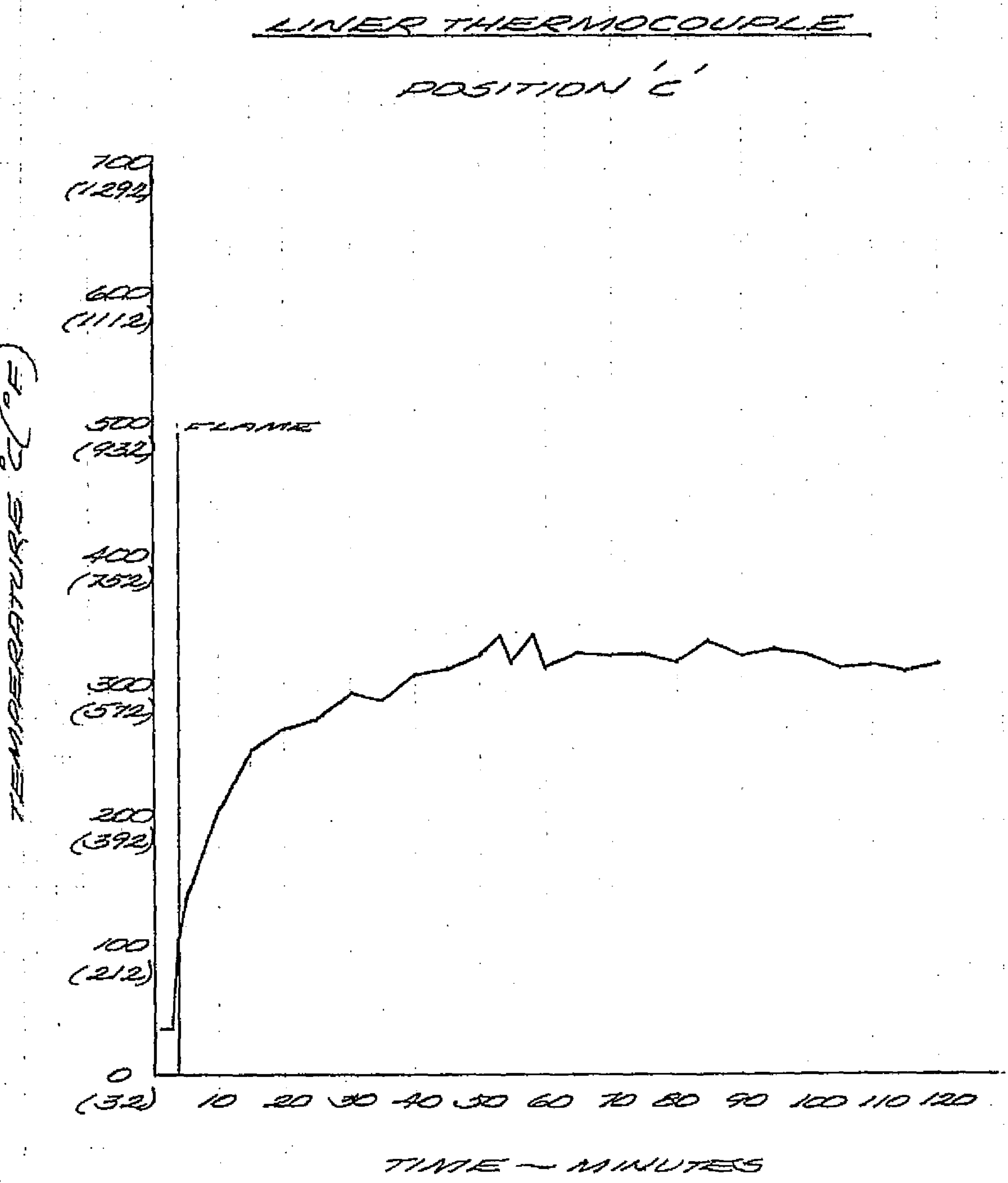


FIGURE 36 LINER TEMPERATURE,
POSITION C - TEST NO. 2)

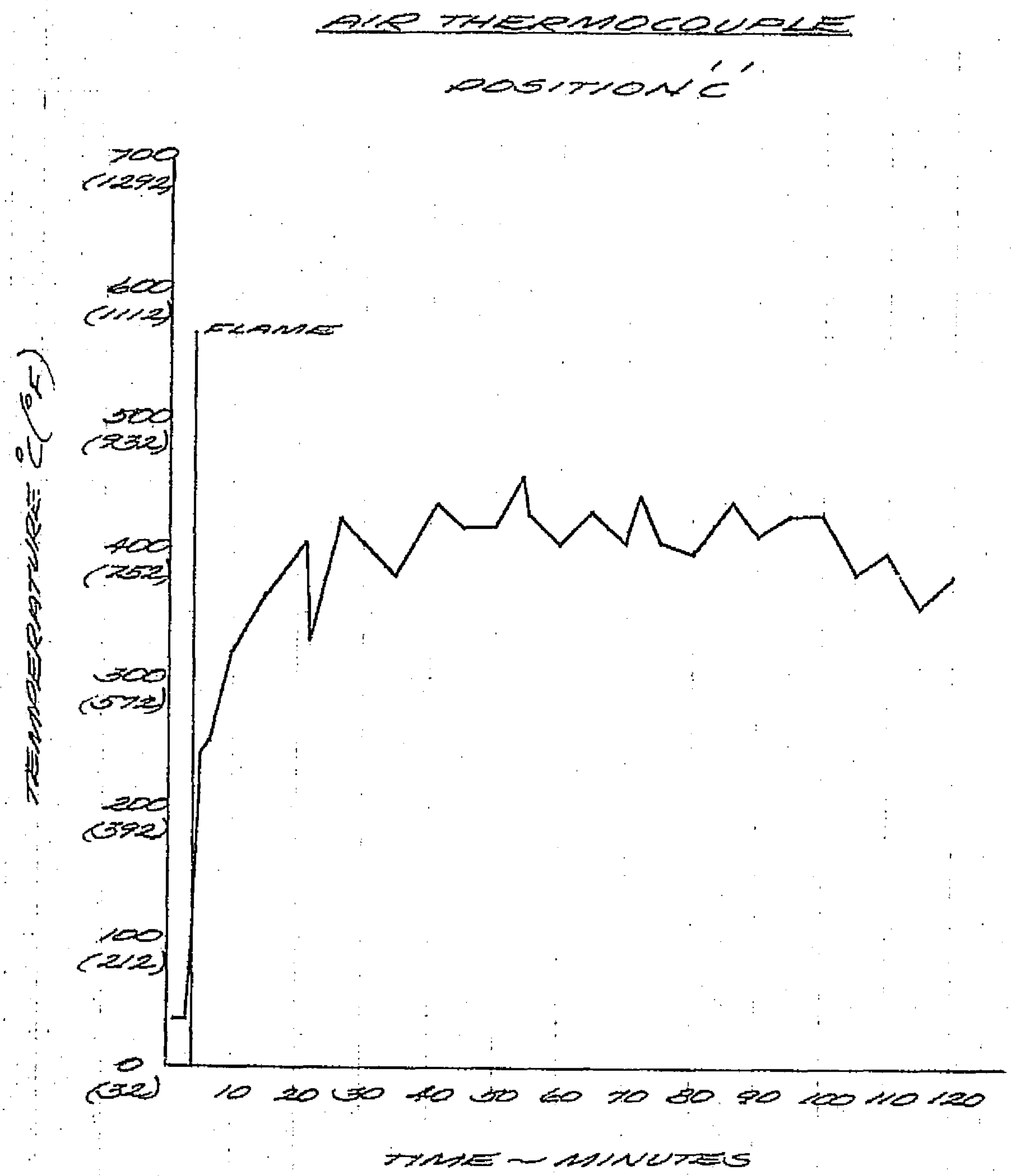


FIGURE 37 AIR TEMPERATURE, POSITION C - TEST NO. 2)

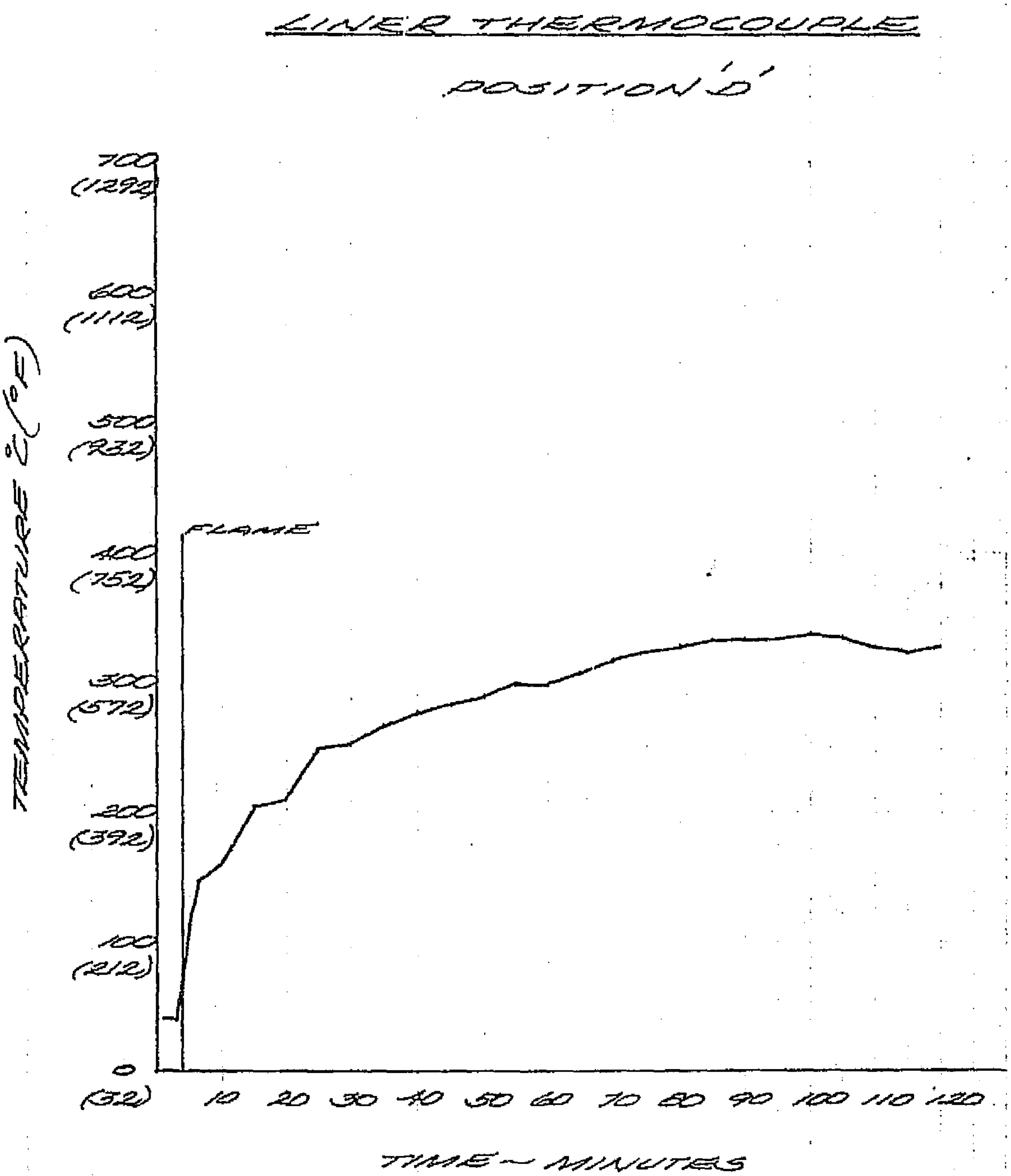


FIGURE 38 LINER TEMPERATURE,
POSITION D - TEST NO. 2)

AIR THERMOCOUPLE

POSITION 'D'

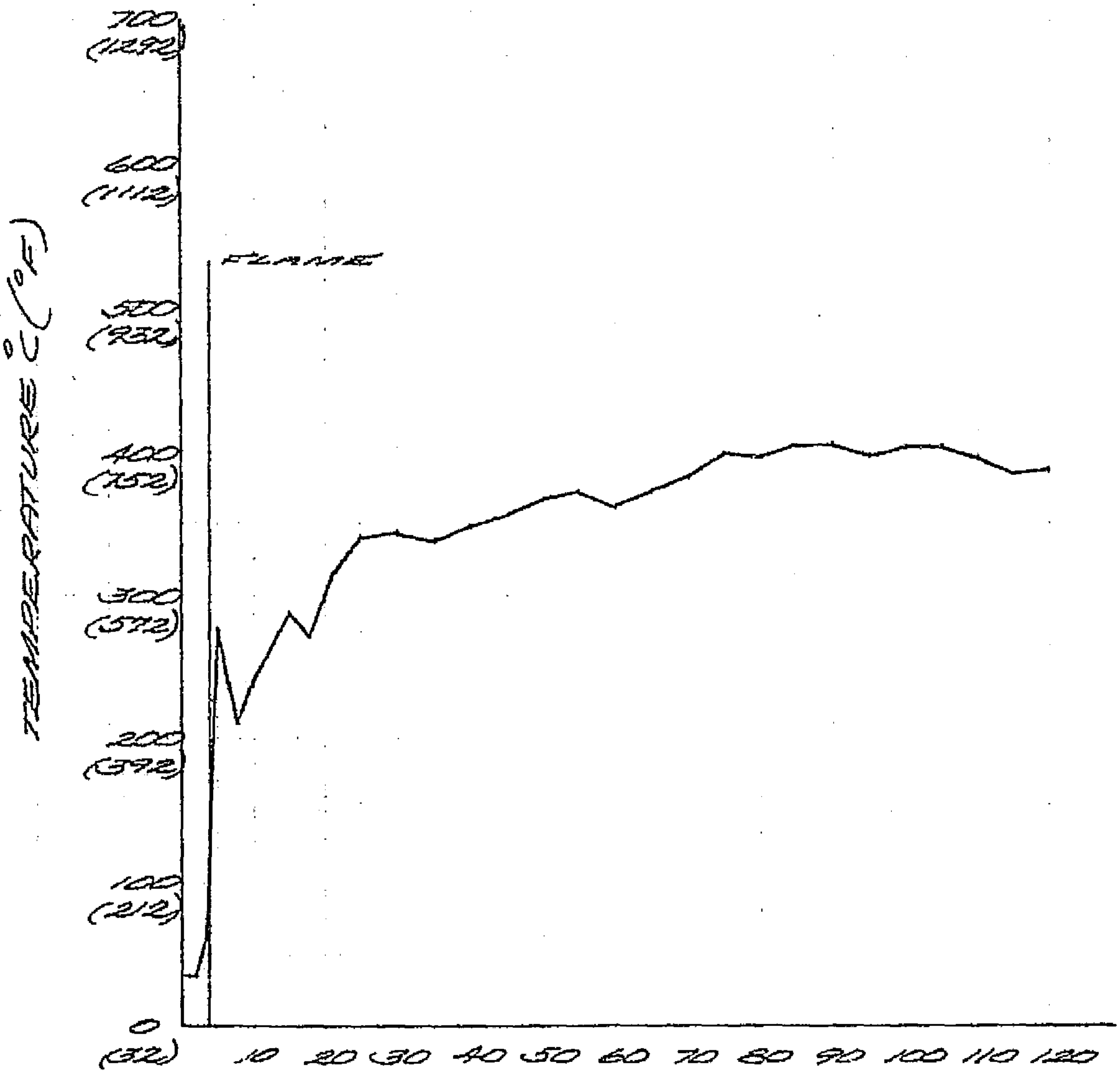


FIGURE 39 AIR TEMPERATURE, POSITION D - TEST NO. 2)

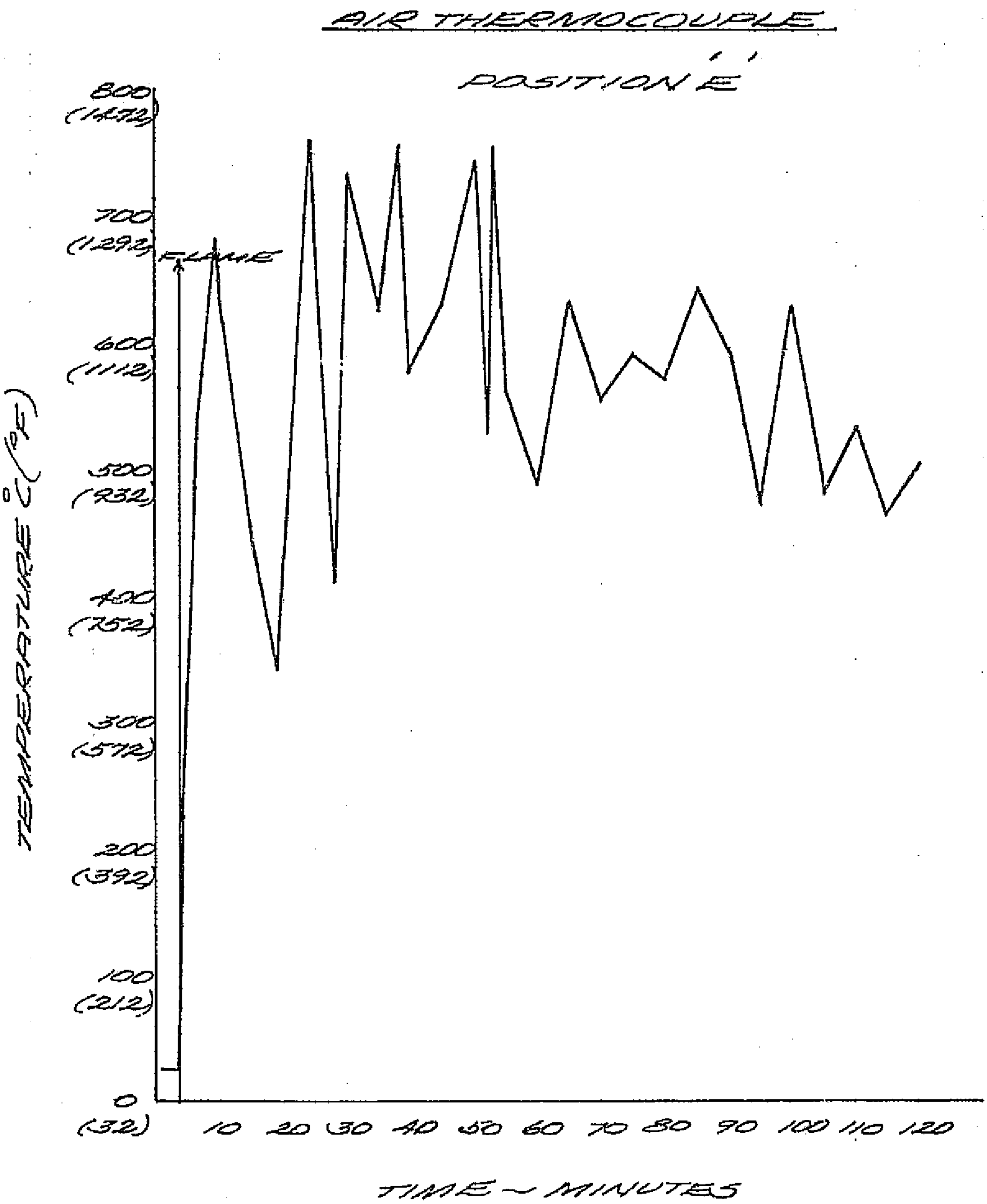


FIGURE 40 AIR TEMPERATURE, POSITION E - TEST NO. 2

ORIGINAL PAGE IS OF POOR QUALITY

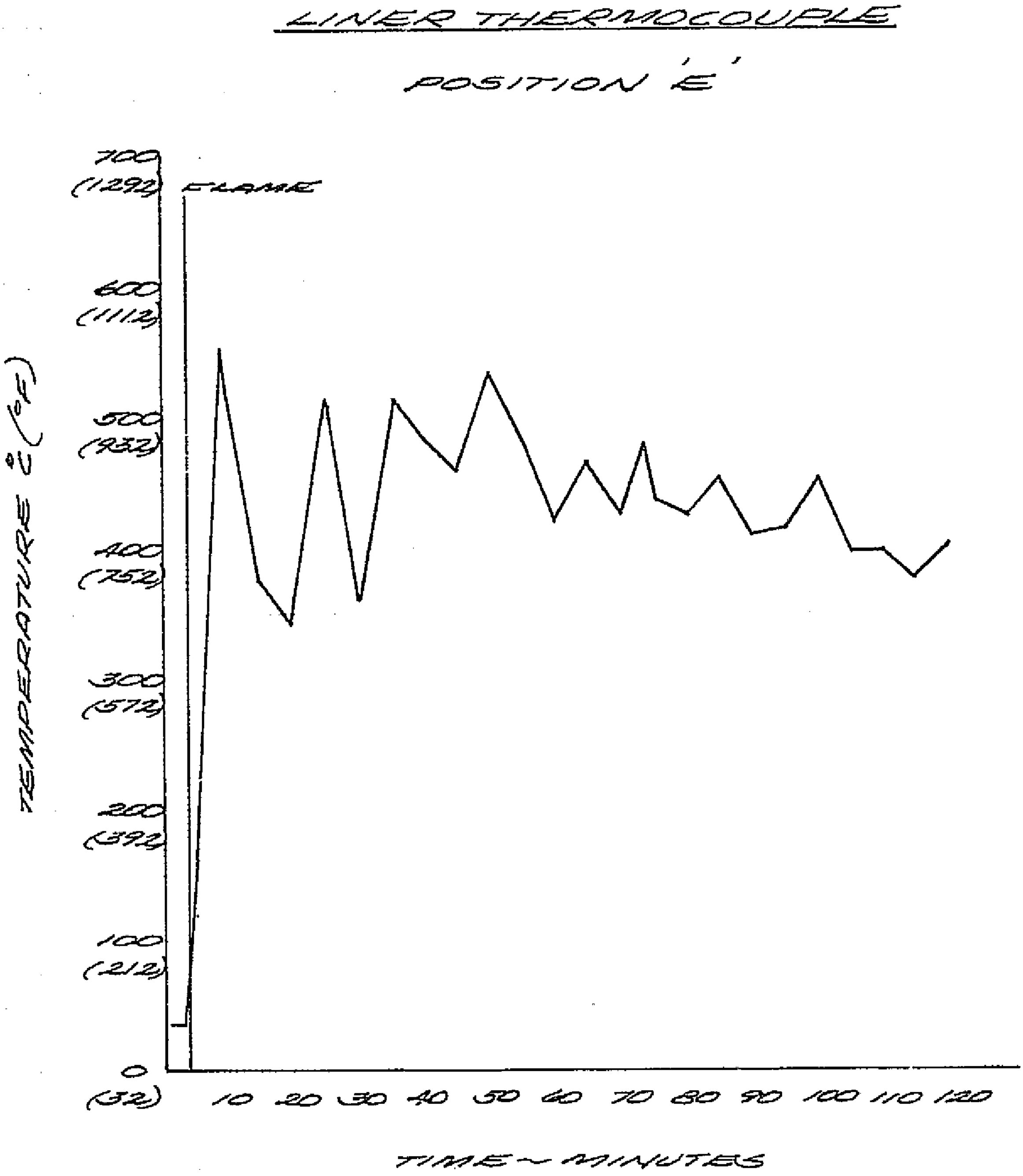


FIGURE 4.1 LINER TEMPERATURE, POSITION E - TEST NO. 2

ORIGINAL PAGE IS OF POOR QUALITY

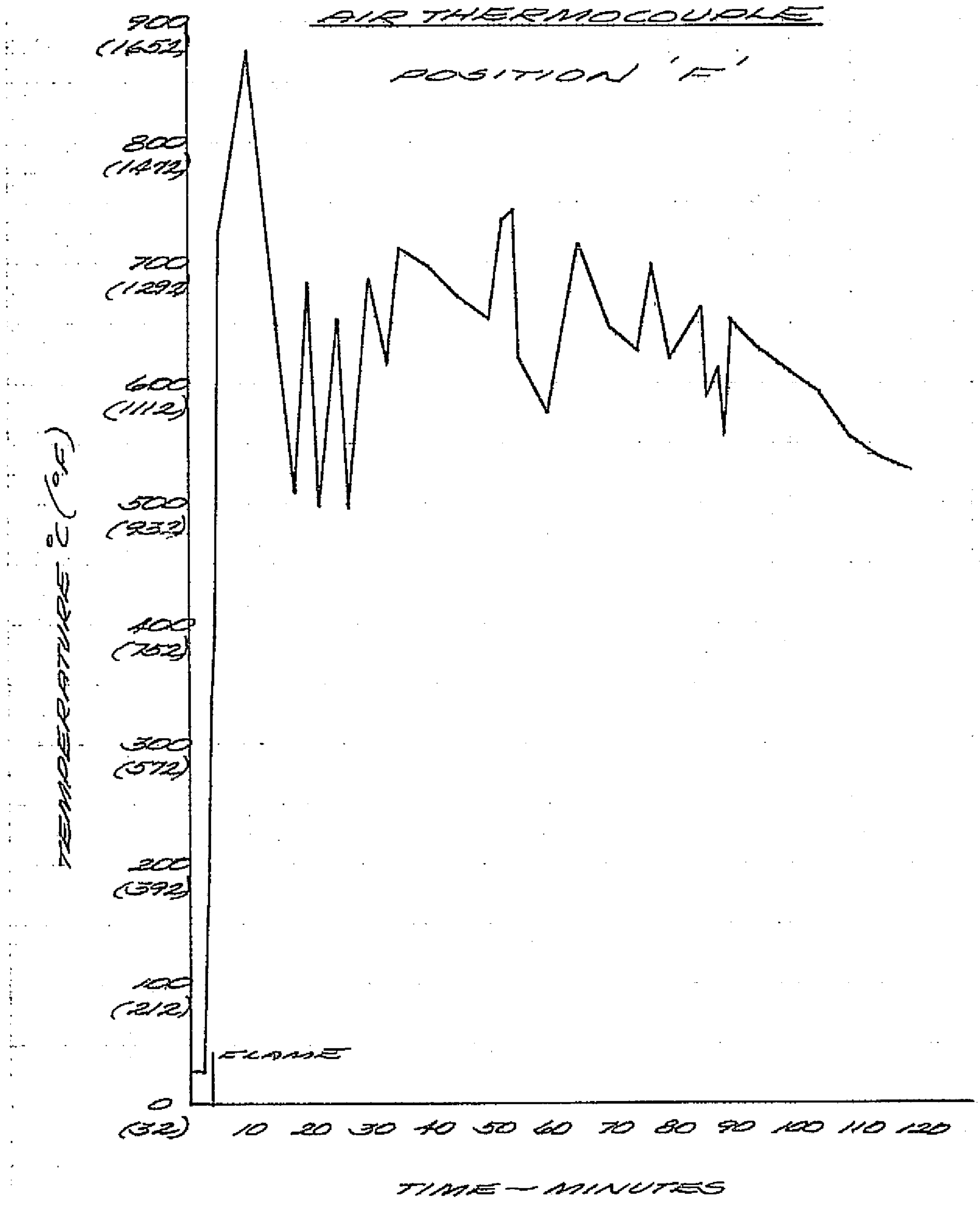


FIGURE 4.2) AIR TEMPERATURE, POSITION F - TEST NO. 2)

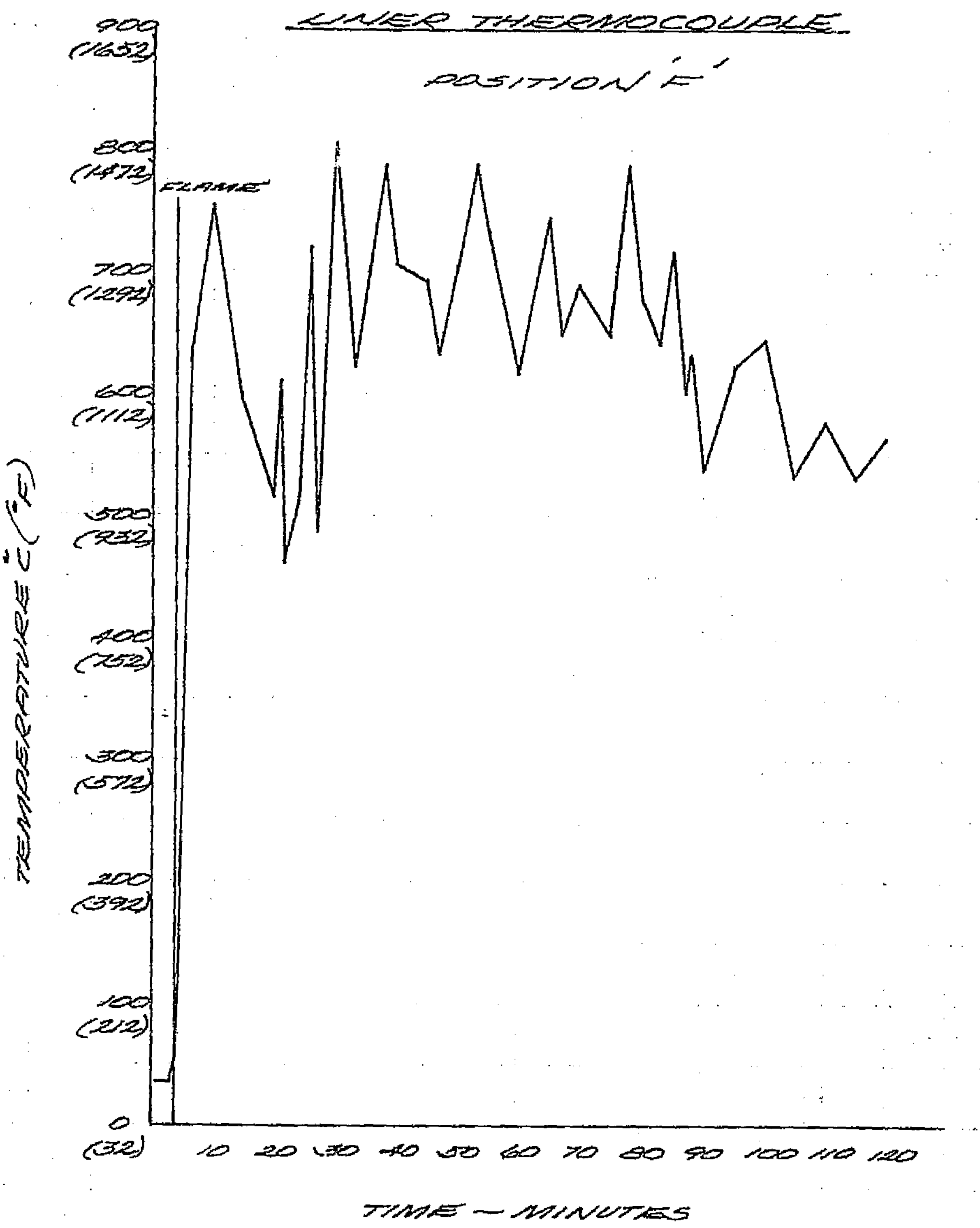


FIGURE 43 LINER TEMPERATURE, POSITION F- TEST NO. 2)

LINER THERMOCOUPLE

POSITION 'G'

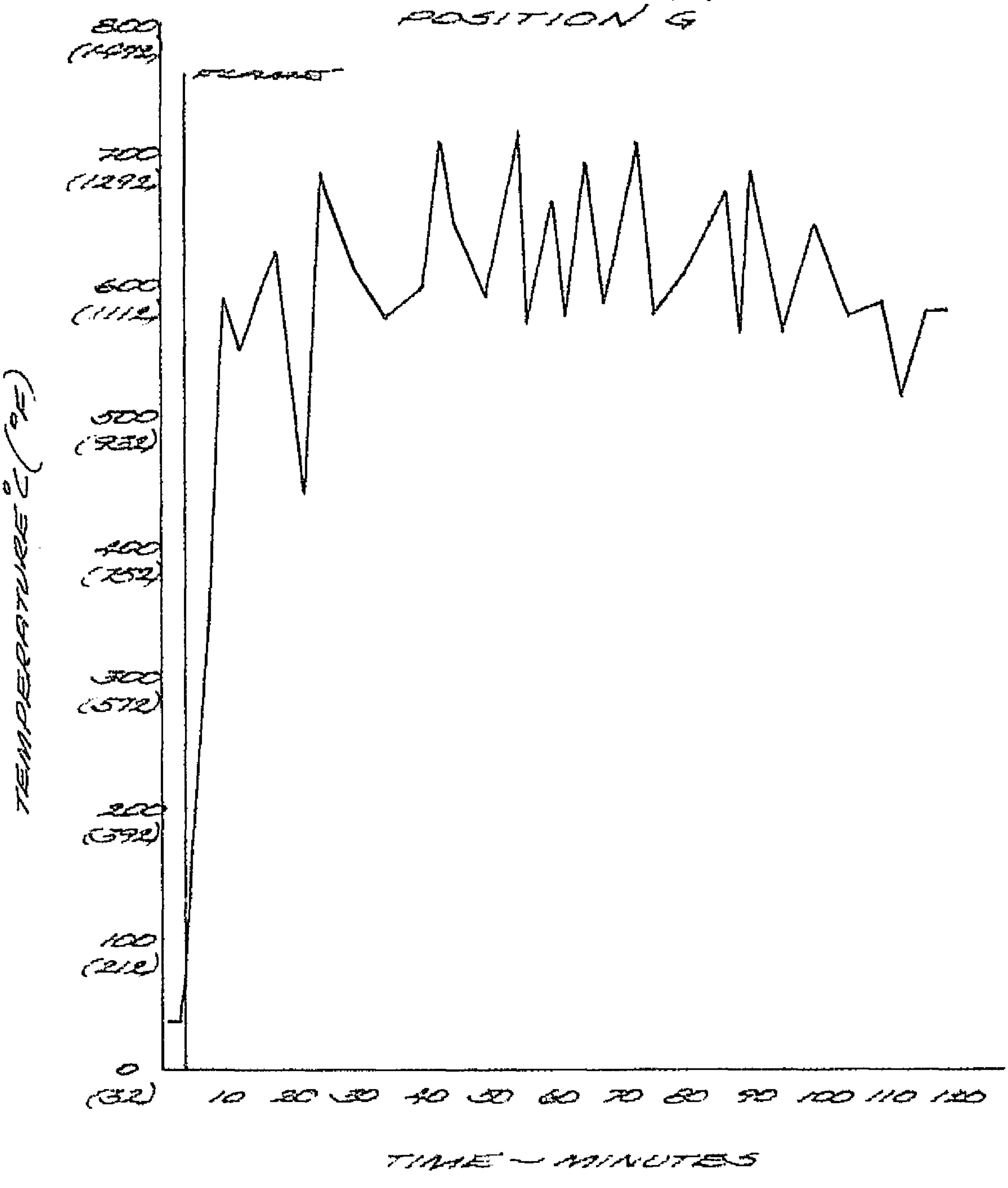


FIGURE 44 LINER TEMPERATURE,
POSITION G - TEST NO. 2

AIR THERMOCOUPLE

POSITION 'H'

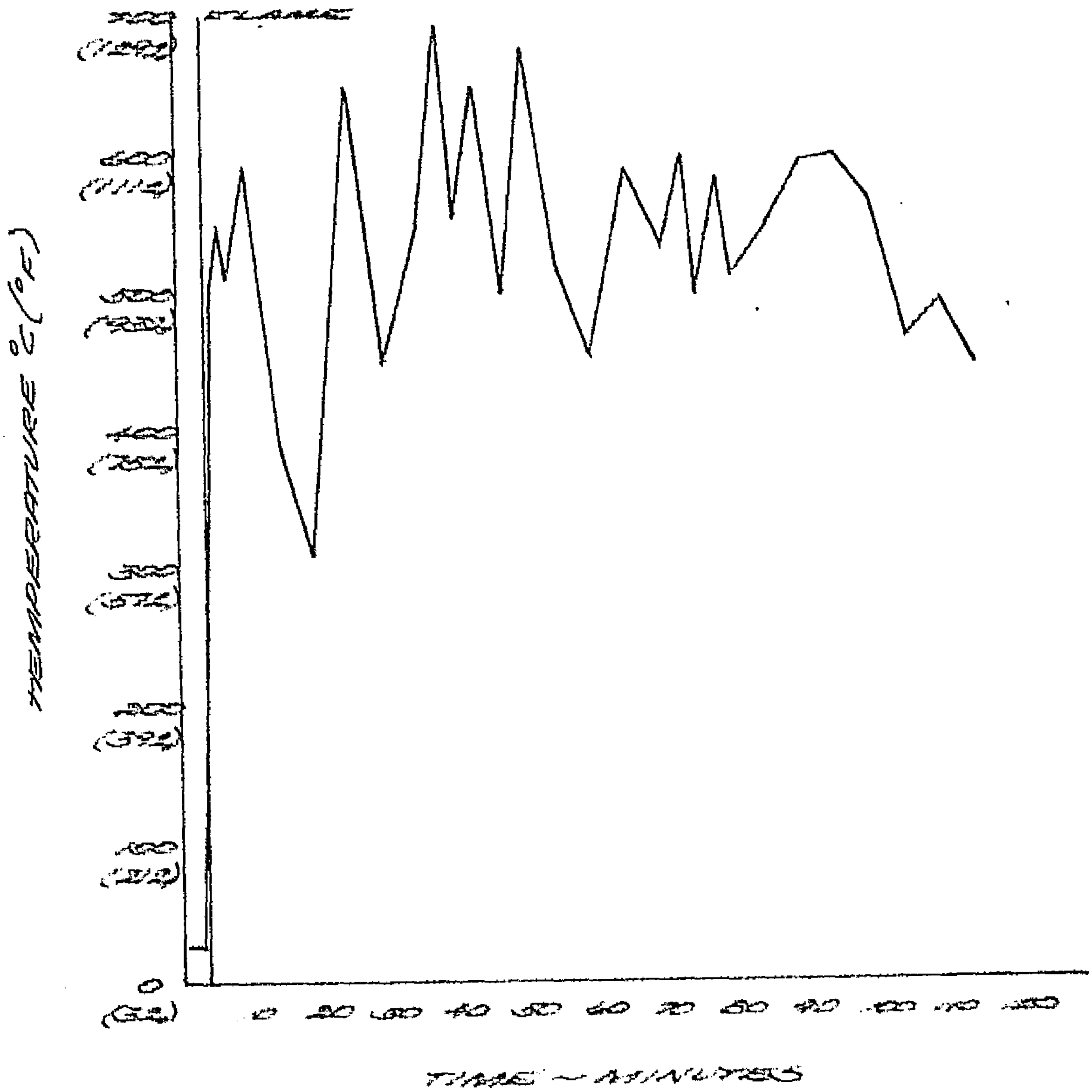


FIGURE 45 AIR TEMPERATURE,
POSITION H - TEST NO. 2

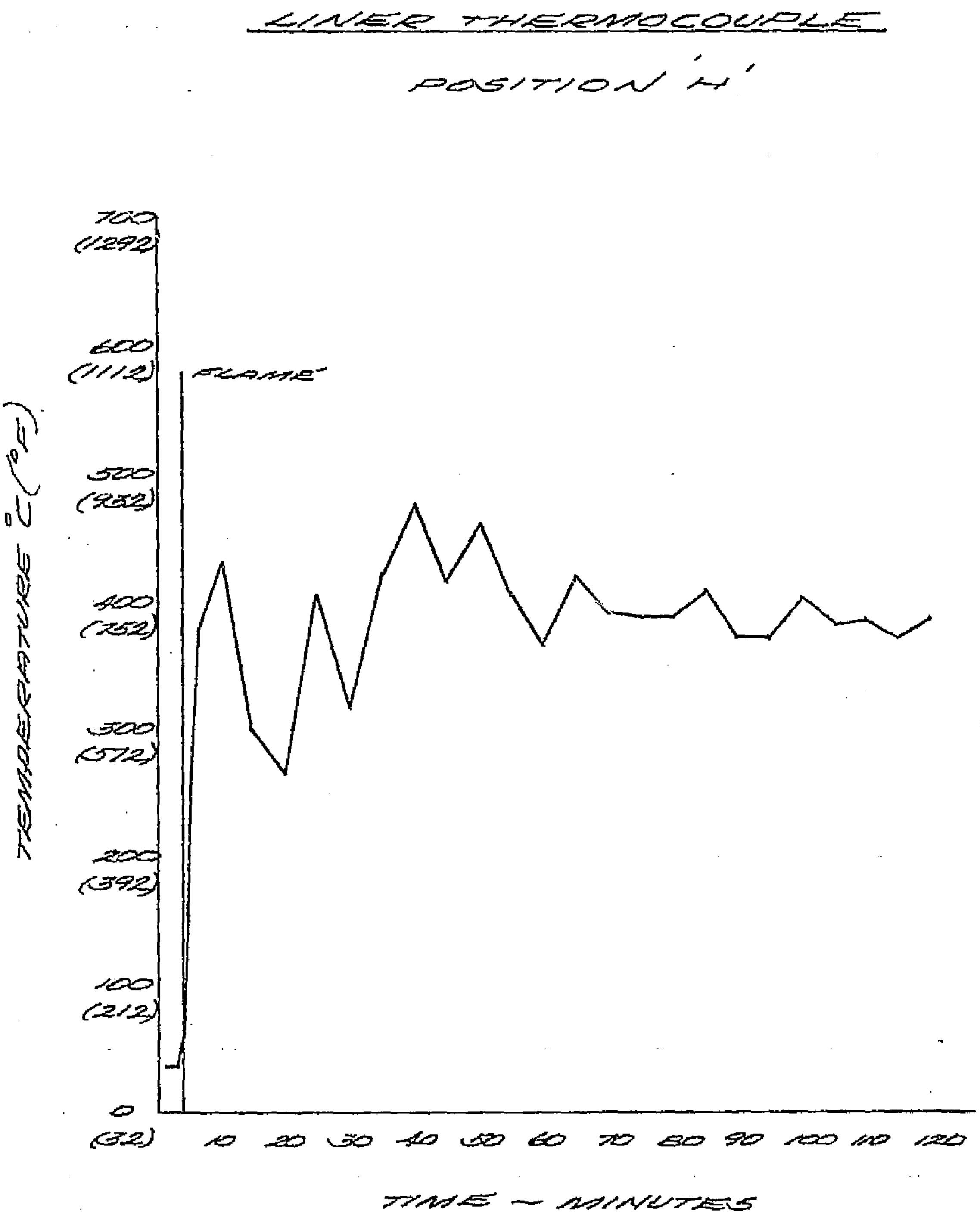


FIGURE 46 LINER TEMPERATURE, POSITION H - TEST NO. 2)

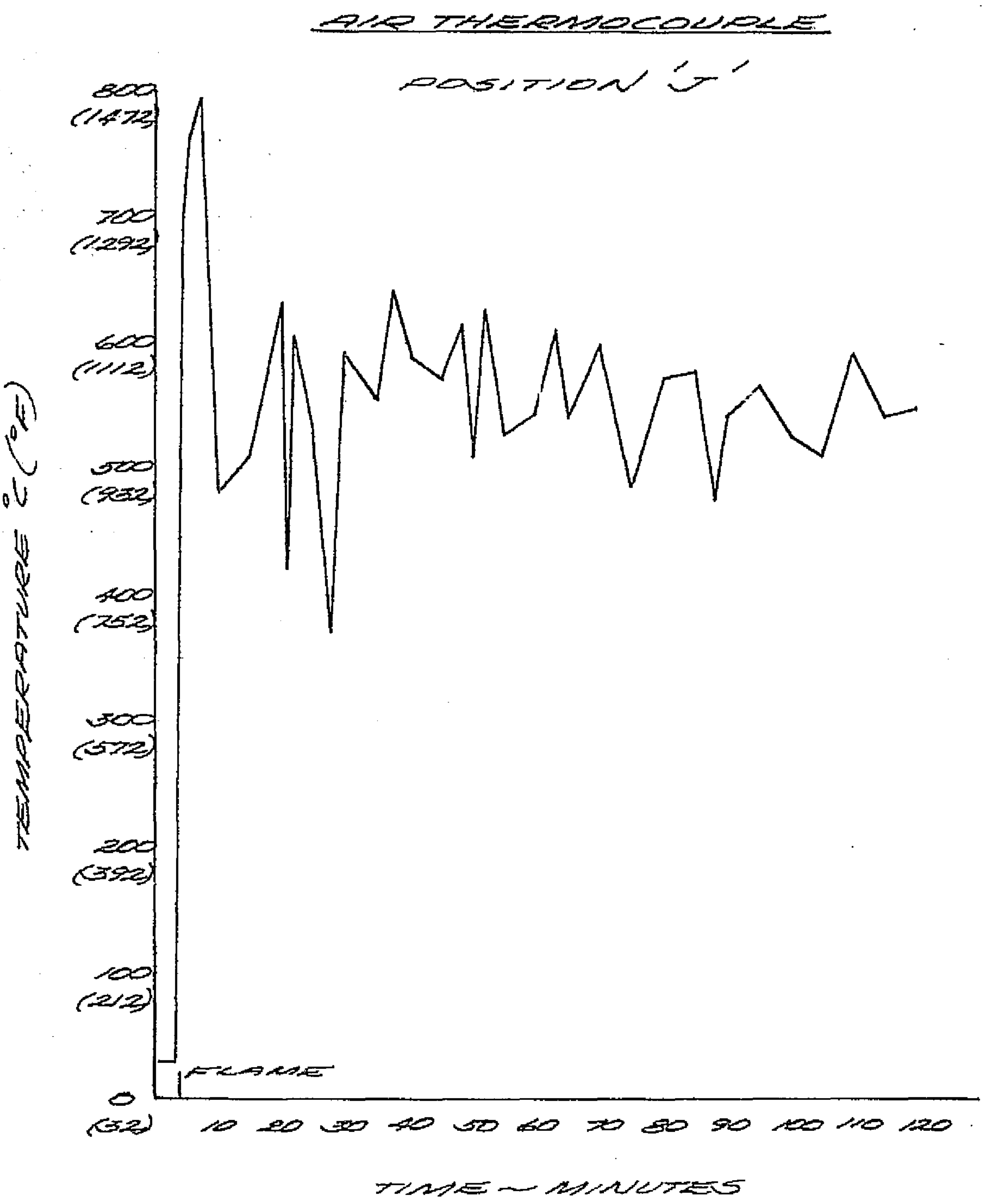


FIGURE 47 AIR TEMPERATURE,
POSITION J. TEST NO.2

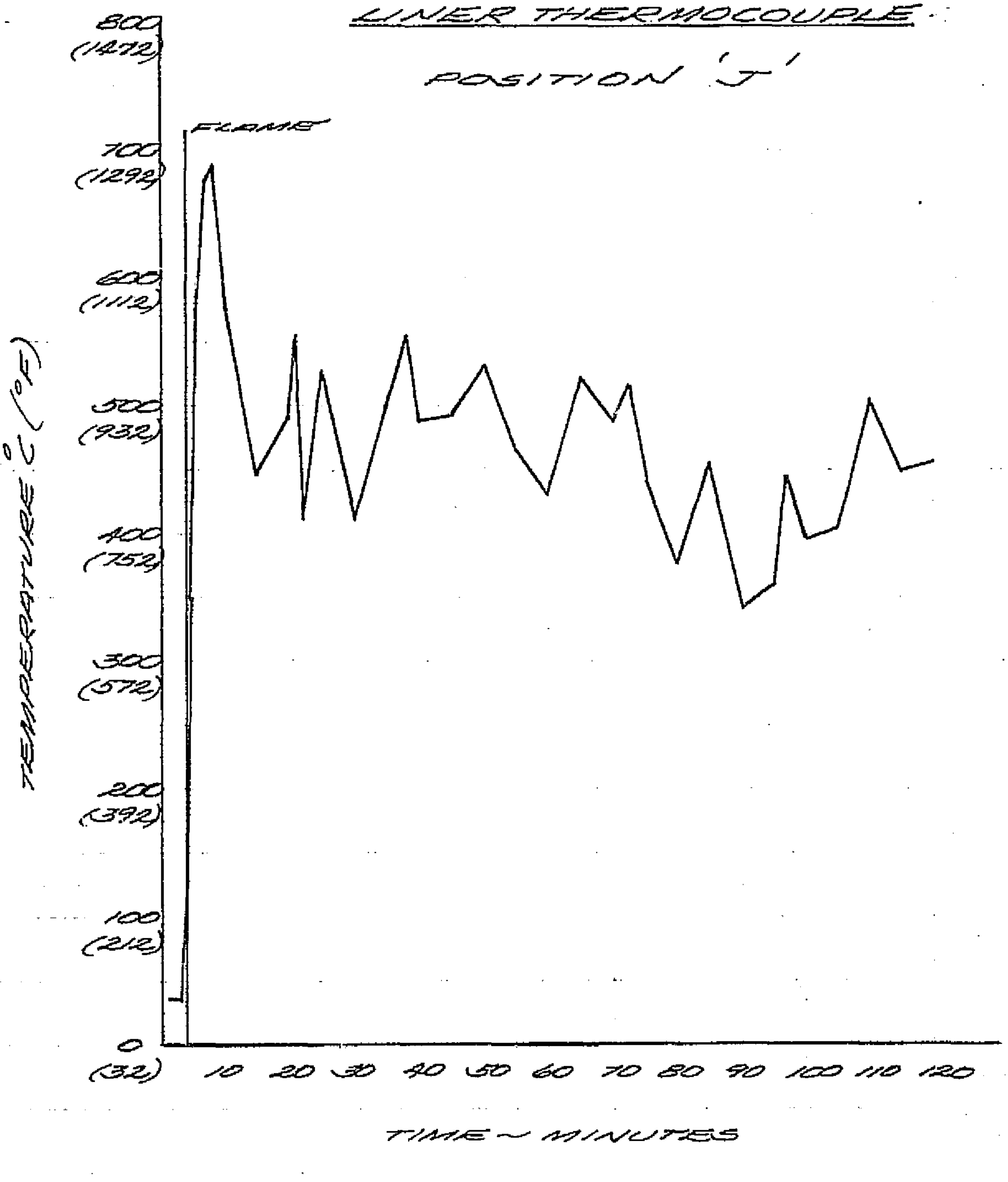


FIGURE 48 LINER TEMPERATURE, POSITION J - TEST NO. 2)

LINER THERMOCOUPLE

POSITION 'K'

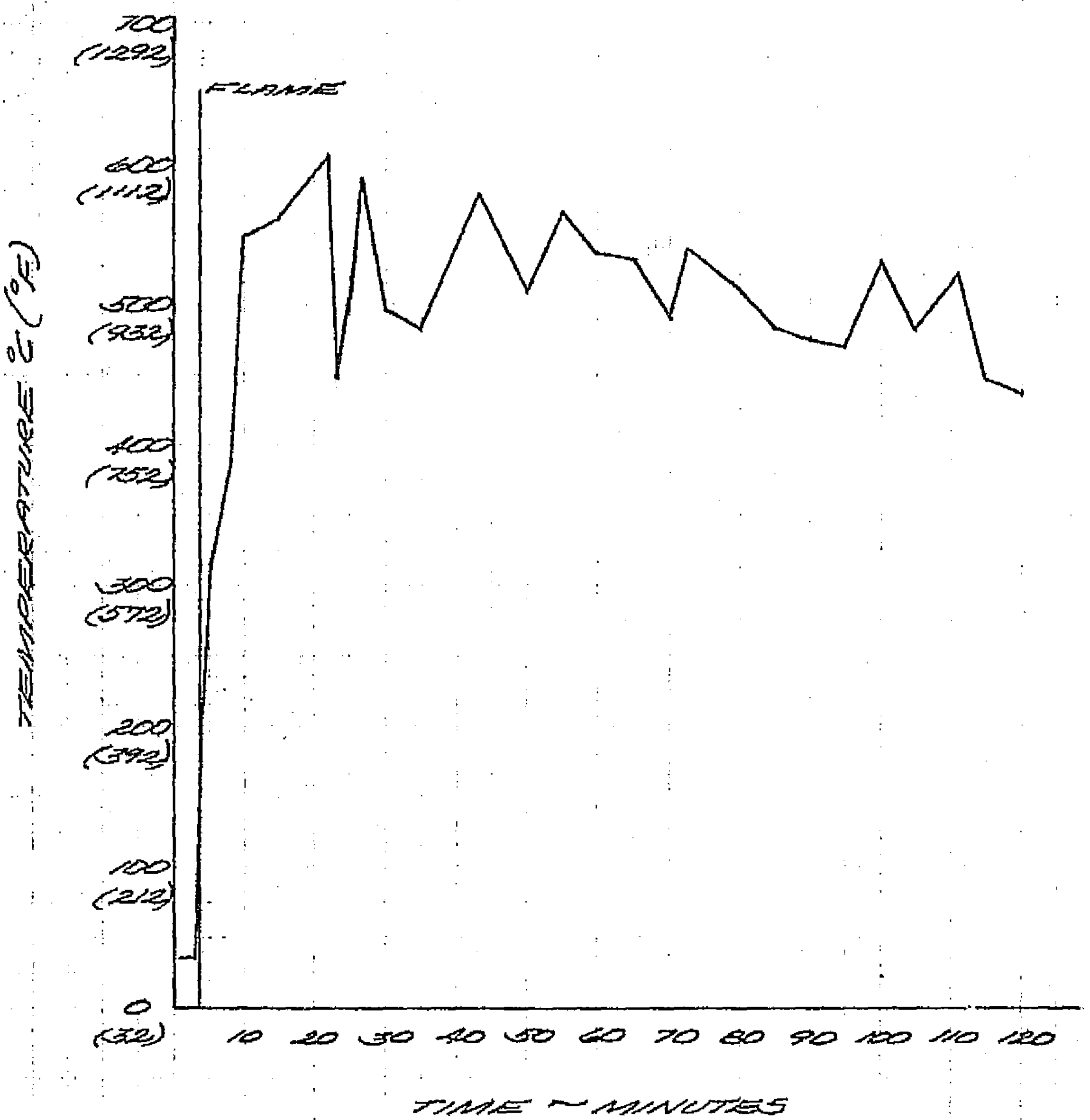


FIGURE 4-9 LINER TEMPERATURE,
POSITION K - TEST NO. 2

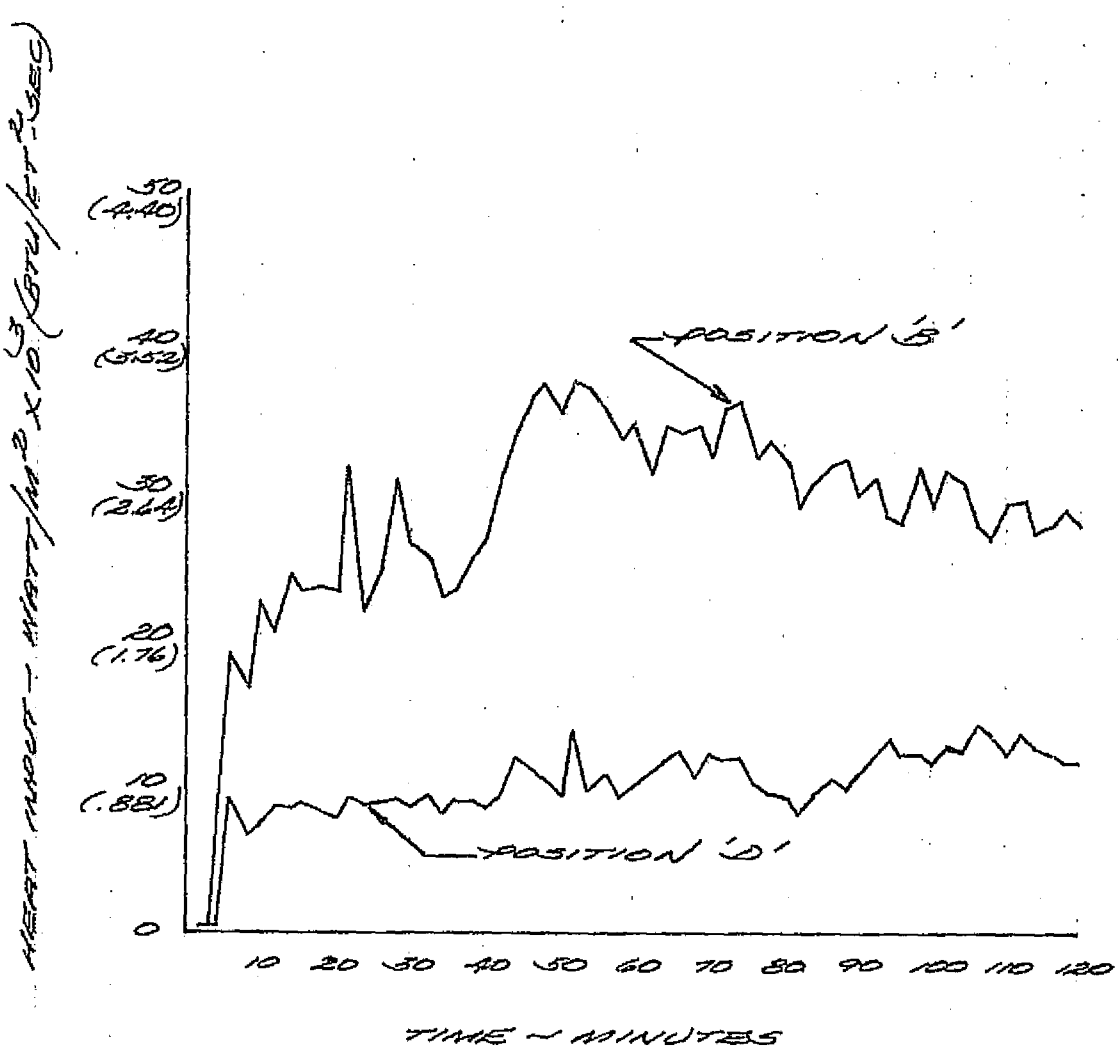


FIGURE 50. HEAT FLUX - TEST NO. 2)

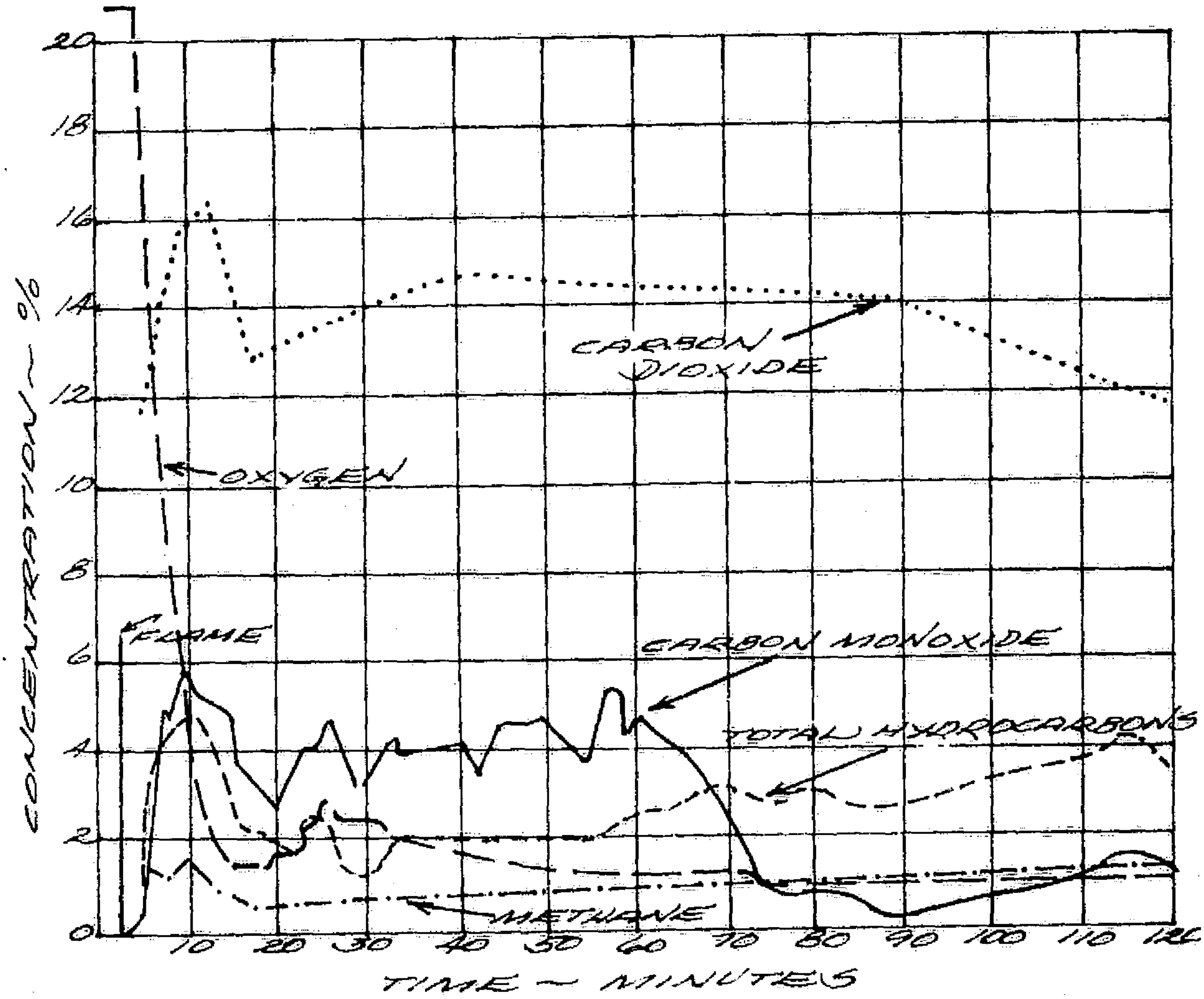
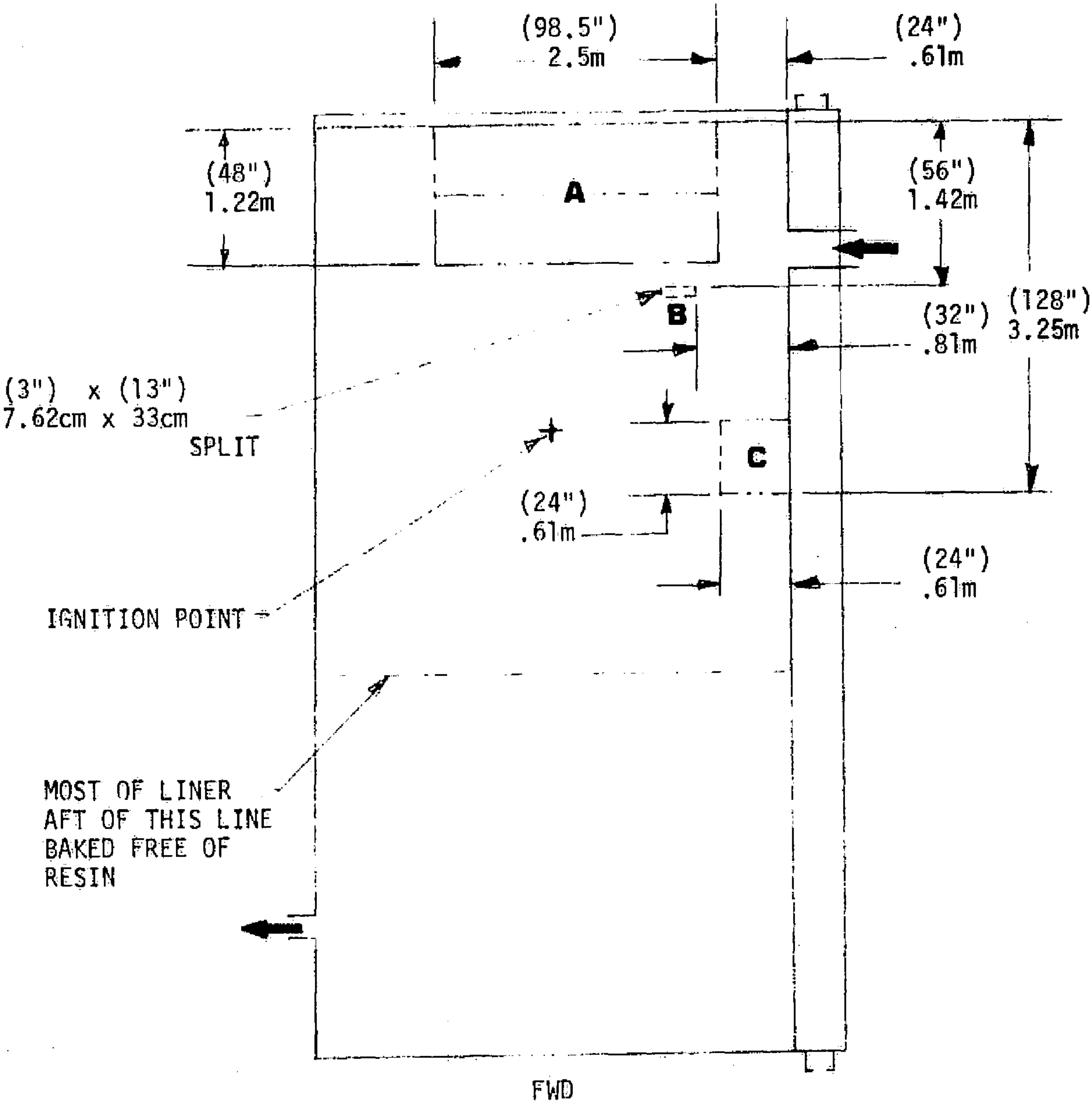


FIGURE 51 GAS CONCENTRATIONS IN CARGO COMPARTMENT TEST NO. 2



PLAN VIEW

REFERS TO FIGURES 53,54 AND 55 FOR PHOTOGRAPHS OF DAMAGED AREAS A, B, & C

FIGURE 52. SCHEMATIC DAMAGED AREAS OF CEILING LINER RELATIVE TO IGNITION POINT - TEST NO. 2

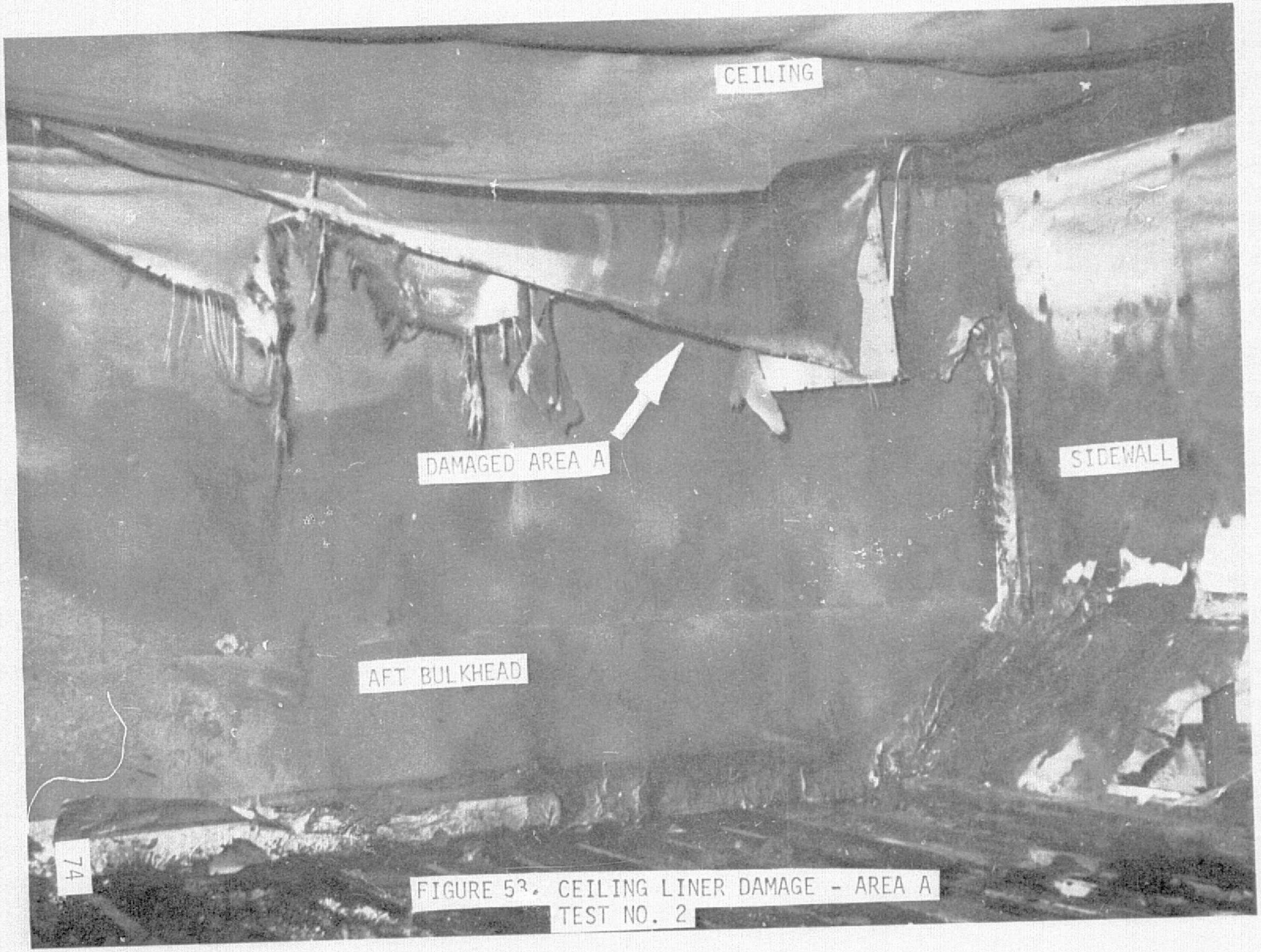


FIGURE 53. CEILING LINER DAMAGE - AREA A
TEST NO. 2

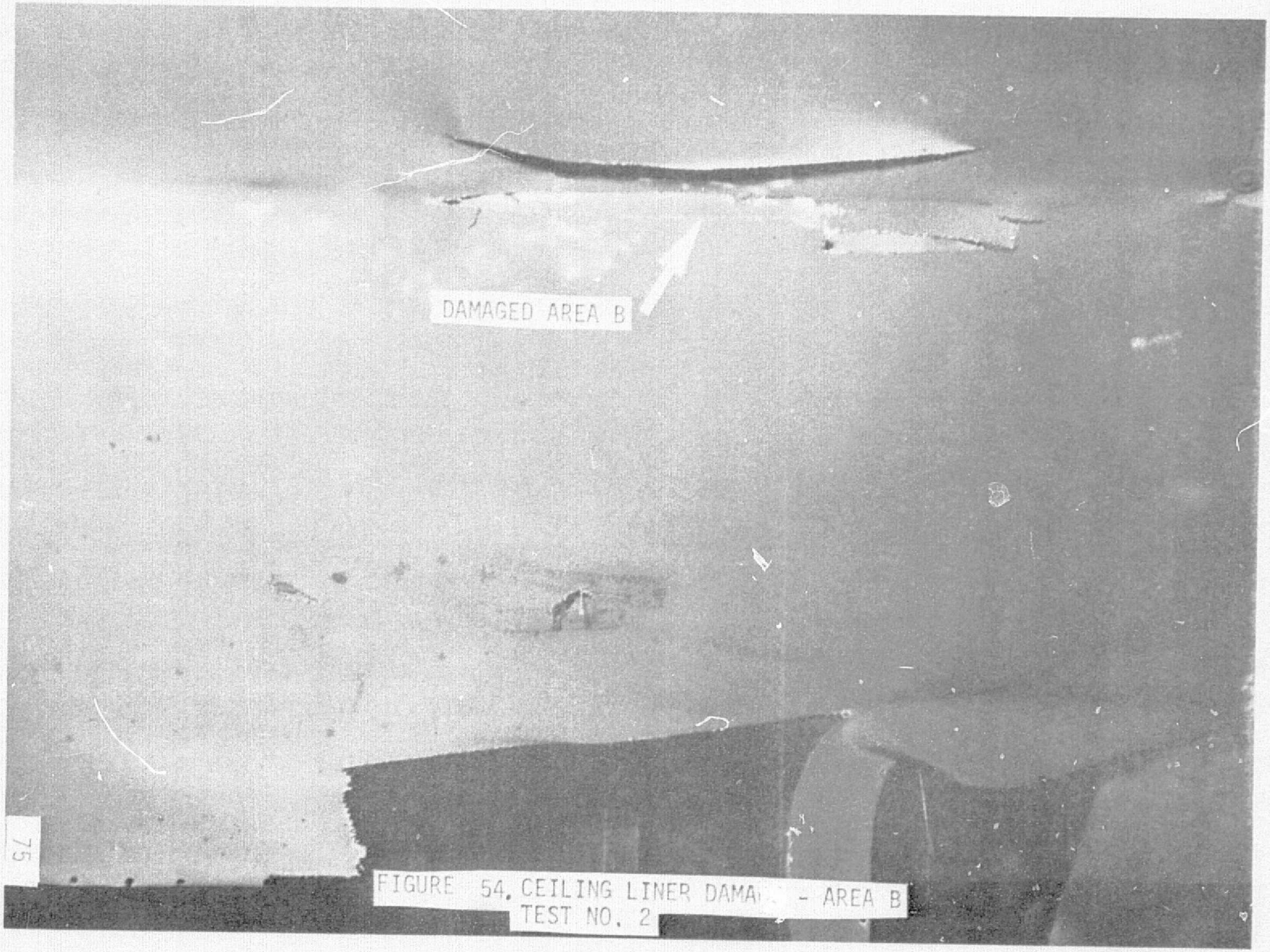


FIGURE 54. CEILING LINER DAMA[illegible] - AREA B
TEST NO. 2

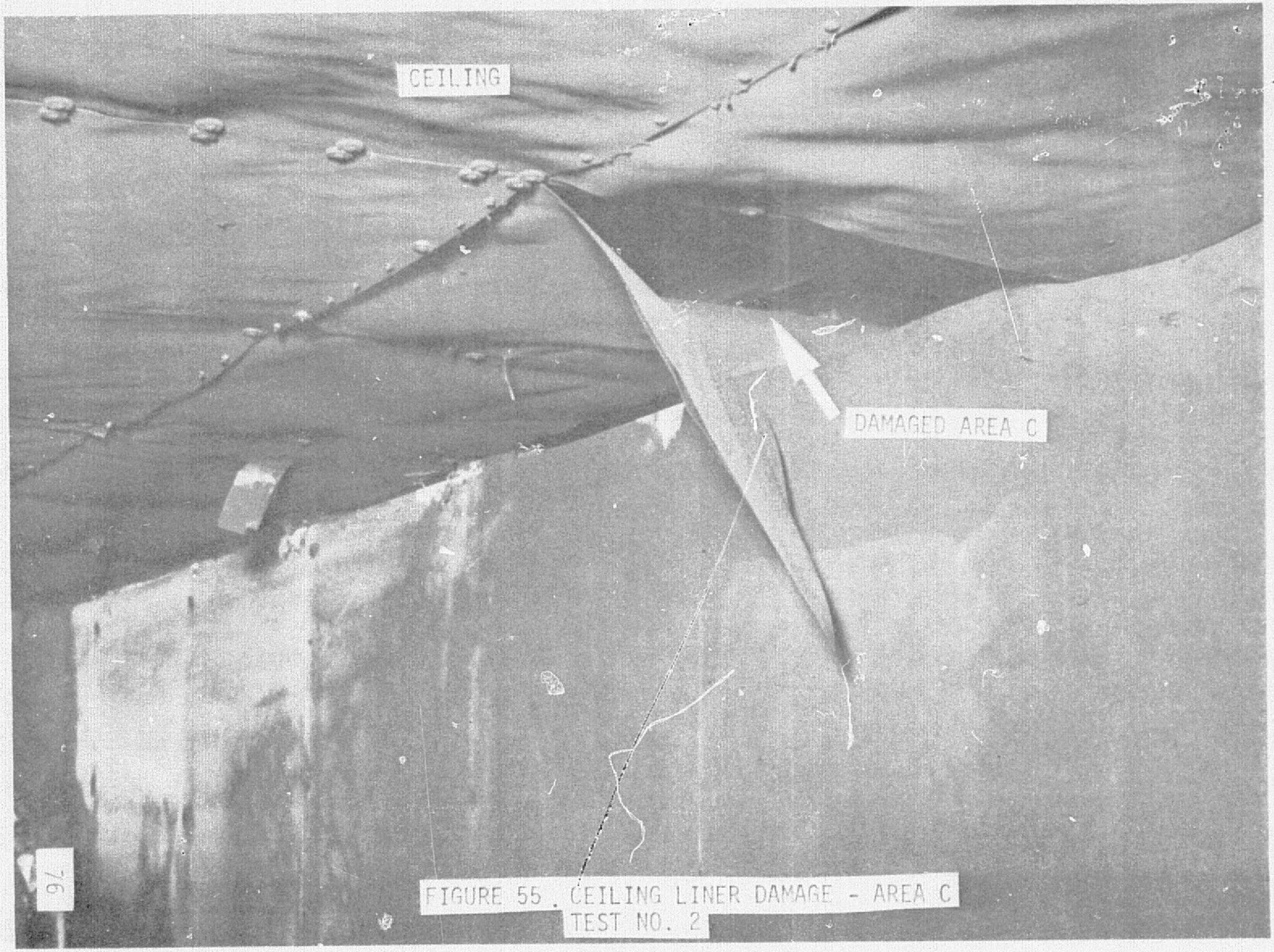


FIGURE 55. CEILING LINER DAMAGE - AREA C
TEST NO. 2

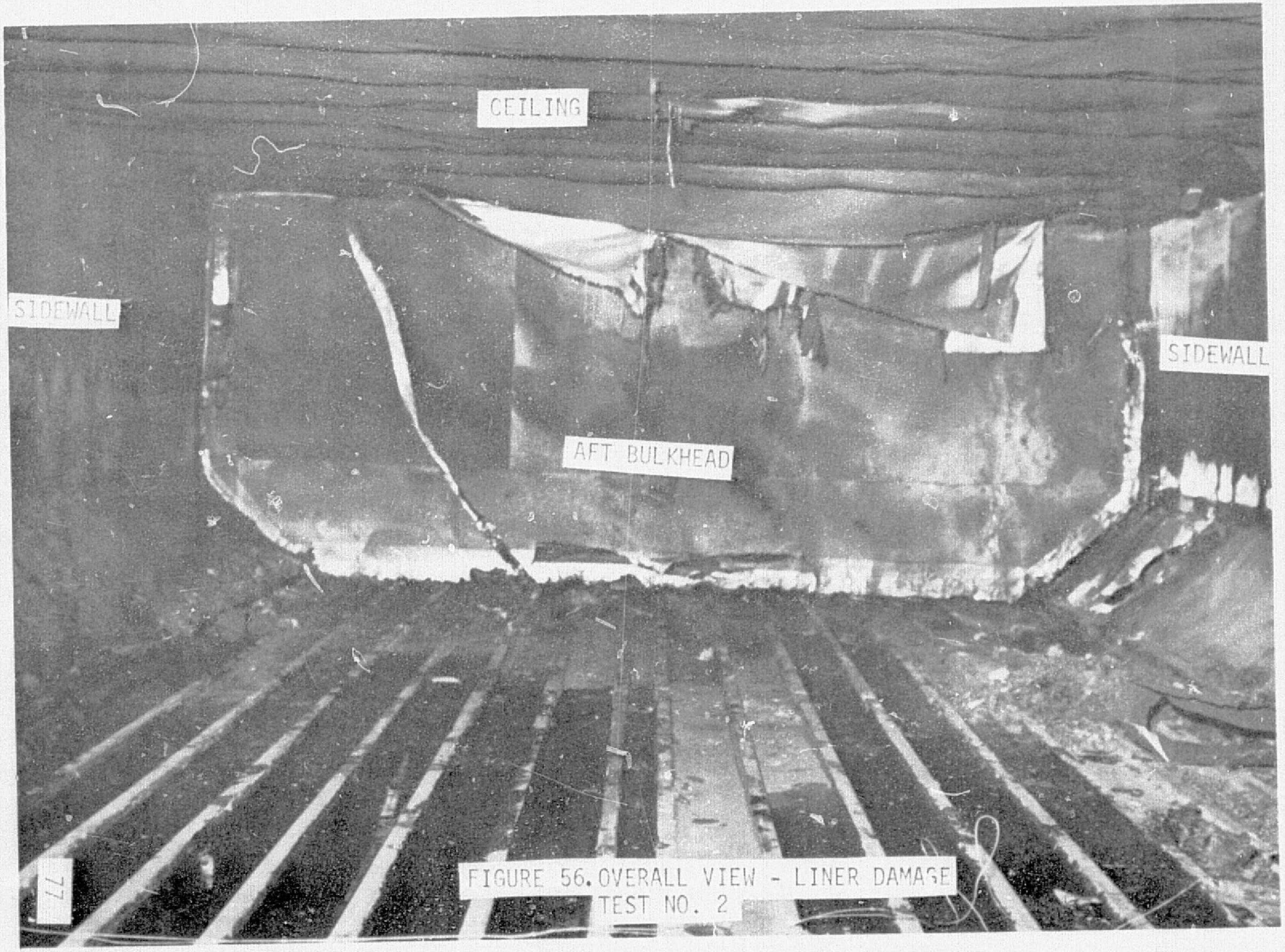


FIGURE 56. OVERALL VIEW - LINER DAMAGE
TEST NO. 2